Development of Relationship Model between Occupant Productivity and Indoor Environmental Quality in Office Buildings in Qatar

Amit Kaushik

(1633081)

B.Arch., MSc.

May 2019

A thesis submitted in partial fulfilment of the requirements of the University of Wolverhampton for the degree of Doctor of Philosophy

This work or any part thereof has not previously been presented in any form to the university or any other body whether for assessment, publication or for any other purpose (unless otherwise indicated). Save for any express acknowledgements, references and bibliographies cited in work, I confirm that the intellectual content of the work is the result of my efforts and no other person.

Signature……………………………………….

Date……………………………………………..

This thesis is dedicated to my parents

For their endless love, support and belief in me

Abstract

The green building and sustainability revolution from the early 21st century provided a significant improvement in building performance and reduced their carbon footprint. When building and operational costs are compared, personnel cost accounts for 85% of the operational cost of any organisation. Major green building guidelines across the world discuss human comfort and health aspects but don't focus on human productivity in the office or other building typology. This gap presented an excellent opportunity to develop a model that establishes the relationship between indoor environmental quality and occupant productivity in office buildings. The study was conducted in Doha, Qatar using experiment and survey using 90 sensors in 15 zones in an office building for a period of nine month. Occupant productivity was captured using online survey with nine questions. Occupant response was analysed against various indoor environmental quality parameters using Response Surface Methodology to outline various relationships. Research study achieved its aim and objectives and produced eight innovative equations that represent the relationship between various indoor environmental factors and occupant productivity. Results also indicate that outside temperature and humidity have an indirect impact on occupant productivity; while temperature, relative humidity and light levels have the most significant impact on productivity. Lux levels have an indirect effect on an occupant's perception of temperature, and outdoor relative humidity has an indirect effect on thermal comfort. Indoor environmental quality factors have direct impact on occupant productivity. This study's unique focus and research design can be used to extend occupant productivity studies in different types of buildings in different climatic regions. It has provided a substantial contribution to the knowledge gap that existed between indoor environmental quality and occupant productivity. Future researchers can use this study to investigate occupant productivity and indoor environment further.

Table of Contents

<u>List of Tables</u>

List of Figure

Acknowledgement

Foremost, I would like to express my sincere gratitude to my supervisor Prof. Mohammed Arif for the continuous support in my doctoral research. I sincerely appreciate his patience and support during all the difficult times in the research study. I am grateful for his motivational skills, immense knowledge and wisdom that he has seamlessly shared with me. His continued guidance helped me in all the phases of my research and I simply could not have imagined having a better advisor and mentor for my PhD.

I would like to thank the thesis committee for their time and critical evaluation of this research study.

I would like to thank my family for their unconditional love, support and blessings that enabled me to continue in tough times. I would also like to thank my friends and university colleagues for their support and discussions that helped in various phases of the PhD journey.

Finally, I would like to thank all the supporting organisations and team members that took part in the research.

List of Abbreviations

- AMA - Alexi Marmot Associates
- ANOVA – ANalysis Of Variance
- ASHRAE – American Society of Heating, Refrigeration and Air-Conditioning Engineers
- BIM - Building Information Modelling
- BOSTI – Buffalo Organisation for Social and Technological Innovation
- BRE – Building Research Enterprise
- BREAAM - Building Research Environmental Assessment Method
- BRI – Building Related Illness
- BUS - Building Use Studies Occupant Survey
- CABE – Chartered Association of Building Engineers
- CASBEE - Comprehensive Assessment System for Building Environmental Efficiency
- CBE – Centre for Built Environment
- CIBSE – Chartered Institute of Building Services Engineers
- DF – Daylight Factor
- DQI – Design Quality Indicator
- FDI – Foreign Direct Investment
- FIFA – Fédération Internationale de Football Association
- GCC – Gulf Cooperation Council
- GIS – Geographic Information System
- GSAS - Global Sustainability Assessment System
- HVAC – Heating Ventilation and Air Conditioning
- IEQ – Indoor Environmental Quality
- LEED – Leadership in Energy and Environmental Design
- OA – Occupational Asthma
- OPN – Office Productivity Network
- PA – Public Announcement
- PMV – Predicted Mean Value
- POE – Post Occupancy Evaluation
- PPD – Predicted Percentage of Dissatisfied
- PPM – Particle Per Million
- RH – Relative Humidity
- RSM – Response Surface Methodology
- SBS – Sick Building Syndrome
- SPL – Sound Pressure Level
- UK – United Kingdom
- UKCMH – United Kingdom's Centre for Mental Health
- USA – United States of America
- VOC – Volatile Organic Compound
- WHO – World Health Organisation

1 Introduction

In a rapidly developing and urbanising world, most people spend most of their time indoors (ASHRAE, 2010a, ASHRAE, 2005). The majority of this time indoors is spent working in an office environment (Oseland, 1999). Research in the built environment sector is widely focused on building performance, but there is a lack of focus on human performance and how buildings can improve human productivity(Oseland, 1999). Building standards and guidelines focus on developing buildings with higher performance and efficiency in energy consumption and carbon footprint (Gou et al., 2014, World Green Building Council, 2014, Deuble and de Dear, 2012). Some building standards and guidelines focus on occupant health, yet there is lack of focus on occupant productivity (Deuble and de Dear, 2012, Miller et al., 2009, Potbhare et al., 2009, Paul and Taylor, 2008). There is a need to investigate the indoor environmental quality and its effect on occupant productivity, which this research sets out to investigate, based in the office buildings located in Qatar.

This introductory chapter presents the introduction to the research, its aim, objectives and questions, and the motivation behind the research. It will also outline the benefits, unit of analysis of the research and explain the structure of the thesis.

1.1 Background

Humans have always endeavoured to build a comfortable and secure habitat. It prompted the built environment's industrial and technological development that led us to the current state of building science and systems. Building science and technologies are continually improving the functionality and aesthetics of the buildings. While this has led to the development of efficient building systems that are comfortable, it requires a focus on human productivity as a result of the comfort provided. Green building design standards and rating systems focused mostly on the environmental performance of the buildings, reducing energy consumption and improving the aesthetical appeal. Most people spend about 70-90% of their time indoors. This is dependent on the area they live, the responsibilities of their job, gender, seasons and age (Heinrich, 2011, ASHRAE, 1993). The time spent indoors is higher for employed adults. For example, American adults spend 90% of their time indoors (Bernstein et al., 2008), while for German children its 75% (Brasche and Bischof, 2005, Javid et al., 2016). Working adults spend a significant amount of their indoor time in their respective workplaces. A workplace's indoor environment has a direct effect on human comfort, which directly impacts on their productivity (Bordass et al., 1993, Leaman and Bordass, 1999, Bordass et al., 2001, Collinge et al., 2014, Tsushima et al., 2015, McCunn et al., 2018) and wellbeing (MacKerron and Mourato, 2013, World Green Building Council, 2014). The quantity of daily time spent at workplace and the effect of indoor environment quality of an office building on occupant led the researcher to focus and investigate the office buildings. The footprint of research and literature on the direct and indirect effect of physical parameters of indoor environments can be found from the early 20th century in Maslow's work (Maslow, 1943), based on his human needs theory and Vernon's work on air quality (Vernon and Bedford, 1930, Vernon and Bedford, 1926). Later, the indoor environment's influence on workplace productivity was presented by Herzberg and Heschong (Herzberg, 1966, Heschong, 1979). In the workplace context, research further outlined the evidence of the extent the impact the built-environment has on an organisation's operational expenses (Romm and Browning, 1994, Leaman and Bordass, 1999, Oseland, 1999, Marans and Yan, 1989). Any organisation's operational costs are divided into personnel, material, financial and building-related costs (Feige et al., 2013). Of these costs, personnel cost has an 85% share of the total cost (CABE, 2005). Studies have shown that employee salaries are more than building and rental costs by a factor of 25 times (Clements-Croome, 2000, Fisk, 2000b). So, improving employees' performance can help to create an extensive amount of savings for the company. In the U.S alone, it is estimated that by improving employees' productivity nationally, there would be a yearly saving of US$ 12-125 billion (Fisk, 2000a). Similarly, in the UK, research outlines that a good office environment can help to improve employee productivity by up to 20%. This amount nationally (UK) reaches a figure of £135 billion per year (Wheeler and Almeida, 2006, Clements-Croome, 2015). Research done by the UK Centre for Mental Health presented the term 'presenteeism'; this describes the state of employees who are present at work, but work at a lower level of productivity. Research also outlines that the indoor environment and its physical factors play a significant role in presenteeism. Nationally, it amounts to £15 billion per year loss (UKCMH, 2011). These factors include thermal comfort, indoor air quality, visual comfort, acoustic comfort and office layout. There are studies that outline the impact of indoor environment quality on occupant comfort and productivity in offices in the middle-east region (Cena and de Dear, 2001, Indraganti et al., 2015, Indraganti and Rao, 2010, Amasyali and El-Gohary, 2016, Al-ajmi, 2010, Mostavi et al., 2017). All of these studies present evidence that outlines how indoor environmental quality affects occupant productivity, a problem that still exists in different countries.

1.2 Research Motivation

As highlighted in the previous section, there is ample evidence of the effects of indoor environments on occupant productivity. This section outlines the gap in current research and rationale behind this research.

Much of the research on building design improvement focuses on sustainability and high-performance building. That research is primarily aimed at minimising the environmental impact by making efficient buildings integrated with various sustainable design principles, high-performance building envelopes, innovative materials and cost-effective technologies. Green building rating systems have a more substantial part of the focal point to minimise the operating cost, by reducing energy cost within the building's operational budget. However, by focusing on both building cost and the indoor environment, designers can reduce both personnel cost and building operating cost for their clients. Most widely-used and respectable building rating systems like Leadership in Energy and Environmental Design (LEED) in the US, Building Research Environmental Assessment Method (BREAAM) in the UK, Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan and Global Sustainability Assessment System (GSAS) in Qatar, include various thermal, air and acoustics quality criteria in their health and well-being category (Potbhare et al., 2009). They are designed to focus on occupant health and maintaining a healthy indoor environment (Varun Potbhare et al., 2009). Currently, design criteria in these building rating systems are focused on the health and well-being of occupants. While these criteria do affect occupant comfort and productivity, their aim is more geared towards the engineering facet of the buildings. For instance, the LEED rating system has thermal comfort, indoor air quality, lighting and daylighting. They focus on water, energy conservation, building material and components, and recycling to reduce the building's impact on the environment (Lee and Guerin, 2009). There is no direct aim to address occupant productivity. Therefore, there is a need to investigate the indoor environmental quality of indoor workplaces to examine its effect on occupant productivity.

Similarly, BREAAM has a focus on health and well-being, assessing visual comfort, indoor air and water quality, and thermal comfort. These factors could result in improving occupant comfort and productivity (Miller et al., 2009). Research studies also outline that green buildings contribute to an increase in comfort levels, well-being and productivity, and reduce absenteeism (Gabay et al., 2014, Clements-Croome, 2004). However, green buildings are not designed to address or improve occupant productivity. It can be postulated that any design criteria for improving occupant comfort can result in increasing occupant productivity. However, research indicates that it is not necessary that optimum comfort leads to optimum productivity. The comfort range of any physical parameter is wider than the optimum productivity range. It is not necessary that optimum productivity and optimum thermal comfort completely overlay within an acceptable thermal comfort range (Fisk, 2000b).

There is a gap between creating a healthy indoor environment for the workplace with low environmental impact and creating a healthy and productive indoor environment with low impact on both environment and client operational cost (Heerwagen et al., 2004, Brill et al., 1985, Leaman and Bordass, 1999, Oseland, 2004, Tanabe et al., 2007, Lan et al., 2011, Wargocki, 2017, McCunn et al., 2018). This presents an opportunity to examine various indoor environmental factors and their effect on productivity in an office.

Every climatic region has a different outdoor environment and requires a unique solution to create a comfortable and healthy indoor environment. Occupant's age, gender, regional weather influences their comfort range

(Quang et al., 2014, Cena and de Dear, 2001). There is a need to focus on a specific type of climate or location.

The researcher has chosen Doha, Qatar, for this research study. Qatar is one of the most rapidly developing countriesin the world (Mason and Lee, 2007, El Mallakh, 2015). In recent years, the development rate has risen dramatically due to the Qatar FIFA World Cup 2022 in Qatar (Kaplanidou et al., 2016). This continuous growth has led to a significant amount of investment from various multinational companies, resulting in extensive real estate development, including office spaces. This research focuses on the Doha climatic region with mixed occupants from various countries. Doha is the capital of Qatar and has a hot desert climate. It has long summer with temperature range 35°c to 45°c. The traditional architecture of this region consists of low rise buildings clubbed to face inwards towards a courtyard (Abdulkareem, 2016). Use of *mashrabiya* screens to cool down the hot air was also prominent in the local architecture (Karamata and Andersen, 2014). The architecture has evolved in recent years due to globalisation and improvement in civil infrastructure of Qatar. There are more towers made up of concrete, glass and steel than traditional buildings with mechanical solutions for thermal and air comfort. These buildings operate similar to any other building in any other climate. However, the interaction between indoor environment and outdoor environment in every climate leads to a different response by the occupant. This interaction and its effect on occupant productivity in the hot desert climate make it unique in its focus and objectives.

1.3 Research Aim

Research problems and motivation have described the gaps in the research and practice of workplace design, with its focus on occupant productivity. There is an opportunity to investigate the relationship between indoor environmental quality and occupant productivity for the industry. Therefore, the aim of this research is:

"To develop a model that establishes the relationship between indoor environmental quality and occupant productivity in office buildings in Qatar."

A list of objectives is proposed by the researcher to achieve the aim mentioned above.

1.4 Objectives

The following objectives have been identified to achieve the above aim: -
The first step is to identify various indoor environmental quality factors that have any effect on occupant productivity. It is essential to define the research scope and breadth of the factors to be considered. This has been done using a literature review.

1. ***To document the indoor environment quality factors and assesses their impact on occupant productivity in an office environment.***

The second objective focuses on identifying different methods that help to measure and capture indoor environmental factors and employee productivity in an office building.

2. ***To document those metrics and methodologies that assess the indoor environmental quality and occupant productivity in an office building.***

Based on the metrics, an experiment will be conducted. The results are then analysed to establish a method to define a relationship model between indoor environmental quality and employee productivity.

3. ***To establish a relationship model (set of equations) between indoor environmental quality and employee productivity in an office building.***

Introductory literature highlighted the inter-relationships and inter-dependencies between different indoor environment quality factors. Further, it will present any inter-relationship and dependency. It would also help to identify the underlying relationship between different types of comfort.

4. ***To outline the inter-dependencies of various indoor environmental factors affecting occupant comfort and productivity.***

Finally, a set of design guidelines and recommendations will be presented for built environment professionals and future research suggestions.

5. ***To develop suggestions and recommendations for built environment professionals to incorporate occupant productivity and indoor environmental quality in office design.***

1.5 Research Questions

The initial investigation led the researcher to confirm that IEQ affects occupant productivity. The researcher aims to answer the following research questions to achieve the aim of this research study:

1. What are the various indoor environmental quality factors that affect occupant productivity in an office environment?
2. What are the metrices and methodologies need to adequately assess the impact of indoor environmental quality on occupant productivity?
3. What is the relationship between indoor environment quality, its factors and occupant productivity in an office environment?
4. How can office buildings be designed to incorporate occupant productivity along with indoor environmental quality?

1.6 Benefits of the Study

The research study would be beneficial in numerous ways to the people in the built-environment sector both in research and academia. The research contributions of the body of knowledge are listed as follows:

1. Contribution to existing knowledge on occupant productivity and indoor environmental quality.
2. This research will contribute to further understanding of indoor environmental quality factors that are important for occupant productivity. It will also highlight the degree of impact of these individual factors.

3. It will contribute to existing knowledge of metrics and methodologies that assess the indoor environmental quality and occupant productivity in an office building.
4. This study will provide future research and develop a direction for the green building rating system across the globe. Currently, no building rating system outlines the IEQ factors that influence occupant productivity. Green building guidelines focus on reducing the energy consumption and carbon footprint. This research study will be a unique effort to contribute a robust study for researchers to develop new criteria for green building rating systems and update the guidelines for office buildings.
5. It will present various mathematical equations for different types of comfort and productivity that establishes the relationship between indoor environmental quality and occupant productivity. The model will be a significant starting point for built-environment researchers for new research endeavours.
6. The research outcomes will be beneficial to architecture and built environment professionals to design a healthy indoor environment for office occupants in Qatar. It will provide recommendations to design better or healthy office spaces. The indoor environmental quality and occupant productivity relationship model (set of equations) can assist designers in creating office buildings in Qatar with higher occupant productivity and satisfaction levels.

1.7 <u>Unit of Analysis</u>

Unit of analysis is a phenomenon to assess the entity that is being analysed in the study. It helps to define the range of analysis conducted in the study as against the unit of sampling that focuses on a sampling of the collected data (Trochim, 2006). There are different levels of analysis, and their units can be defined using the nature and characteristics of the study. This study aims to map the relationship between indoor environmental quality and occupant productivity in office buildings in Qatar. It is a quantitative study in a longitudinal time frame. The analysis is presented using productivity as a basic unit. In this case, a five level scale has been used to define the productivity from very negative to very positive. The data is collected at the individual level using survey but analysed at group level to define the cause-effect relationship. The scope of the research is limited to the physical environment and its impact and does not include the behavioural environment and its impact on productivity of the occupants. The analysis is focused on the regional (Qatar) level due to the impact of external weather on occupant perception and response to indoor environmental quality. The unit of analysis of this research study is office buildings in Qatar.

1.8 Overview of the Thesis

This section provides an overview of thesis chapters. The chapters are structured to represent the sequence of the research study and are inter-related. A brief outline of the chapter covered in this research is given below (Table 1.1):

Chapter	Description
Chapter 1: Research Introduction	This chapter provides an introduction to the research study. It covers the research motivation, aim, objective and questions. It also presents the benefits of the research.
Chapter 2: Literature Review	This chapter presents a comprehensive literature review of the study. It presents the state of the art literature on all five indoor environmental factors that affect occupant productivity.
Chapter 3: Research Methodology	This chapter presents the research methodology of the study. It covers various aspects of methodology such as research design, analysis, and approach. It also presents the equipment used for data collection and the occupant profile.
Chapter 4: Result and findings	This chapter presents the results and findings of response surface methodology conducted on eight physical parameters under five indoor environmental quality factors reviewed in the literature review.
Chapter 5: Discussion	This chapter presents the discussion of results.
Chapter 6: Conclusion	This chapter presents the attainment of

and Recommendations	research objectives, research conclusion, research limitations, research contributions, the recommendation for future research

Table 1.1Overview of the thesis

1.9 Chapter Summary

This chapter outlines the current gaps in the research and focuses on occupant productivity. It also presents the potential benefits of focusing on occupant productivity, while designing a healthy indoor environment in the workplaces. Currently, no green building guideline explicitly focuses on occupant productivity and provides a building rating. The aim, objectives, research questions and benefits of the study have been presented. The following chapter covers the literature review, presenting the current literature and research available on indoor environmental quality and occupant productivity.

2 Literature Review

This chapter presents the literature review of the research study. The chapter is divided into seven sections outlining the effects of five IEQ factors on occupant productivity. The first section introduces the literature. A section on thermal comfort follows it, which outlines the thermal comfort parameters and reviews their effect on occupant productivity. The third section describes the indoor environment quality parameters and their effect on occupant productivity. The fourth section focuses on visual comfort. The fifth section presents the effect of Acoustic Comfort on productivity. The sixth section describes how an office layout impacts occupant productivity. Finally, the last section summarises the literature review.

2.1 Introduction

The previous chapter outlined the gap in current literature and practice of building design. It highlighted that various design guidelines lack a focus on developing design criteria about occupant productivity. Overall, there is a sense of awareness about indoor environmental quality and its effect on occupant productivity. However, there is a need to investigate and outline such design guidelines.

2.2 Productivity

It is essential to understand productivity to investigate this topic further. It is the ratio of output to input. Productivity varies as per the context and content of the input and outcome (Kotler et al., 2006). In the case of organisations, productivity can be measured as the ratio of money spent on employee cost to company turnover (Oseland, 1999). Productivity in an office environment is measured at the individual, team and company level (Feige et al., 2013) and is affected by four factors; personal, organisational, social and environmental. The degree of impact of each factor, any interdependencies and interrelationships cannot be mapped (Williams and Clements-Croome, 2006, Clements-Croome, 2000). However, research studies indicate that conducive environmental conditions in offices lead to a reduction in absenteeism and employee complaints, and increase employee productivity (Lorsch and Abdou, 1994, Tse and So, 2007, Zhai et al., 2015). The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) outline that any office environment is treated as a healthy indoor environment when 80% of its occupants are satisfied with the environment (ASHRAE, 2004). Occupant satisfaction with the physical environment is directly related to its comfort levels (Frontczak et al., 2012, Choi et al., 2009).

If we look at comfort, it is characterised by the state when there is no unpleasant sensation. Comfort is a complex subjective state, affected by numerous physical factors (Freire et al., 2008). In an office environment, comfort is dependent on the following factors (Feige et al., 2013).

1. Psychological comfort

   It includes psychological factors like privacy, territoriality. The occupants need to feel safe and have privacy in an environment to be productive. They also need to feel some sense of ownership of the place.

2. Functional comfort

   The occupants need an interruption-free workplace environment with adequate resources. The functionality of a workplace also depends on disturbances in the workflow and the convenience in accessing the workplace.

3. Physical comfort

   Physical comfort includes physical parameters of the indoor environment like temperature, humidity, air quality, noise and lighting levels.

Oseland described comfort in an office space as a combination of physiological, psychological and physical environmental conditions. He further details out physical environment into the following (Oseland, 1999):

1. Physical conditions

   These are the physical parameters of an environment. They include an indoor temperature, lighting level, indoor air quality and sound levels.

2. Space

   Nature and efficiency of the space designed for indoor workplace also affect the productivity and comfort of the occupants. It includes aspects such as a representation of workflow in the office design using layout, privacy and a disturbance-free environment.

3. Ergonomics

   Ergonomic factors like workstation design, control over a workstation and its furniture also contribute to improving the comfort and productivity of the occupants.

Occupant comfort is a result of functional, environmental and personal health factors (physical and mental) (Leaman and Bordass, 1999, Clements-Croome, 2006). Apart from physiological aspects, the behavioural environment also affects occupant comfort. Every space occupants share has its behavioural environment. Subjective elements, such as behavioural and social aspects of an indoor environment also influence occupant comfort (Haynes, 2007b, Fleming, 2004). These aspects include preferences on behaviour elements like interaction frequency, collaboration opportunities, privacy and distraction tolerance (Brenner and Cornell, 1994, Heerwagen et al., 2004, Haynes, 2007a). The behavioural environment of an office influences occupant behaviour and social norms. It is an integral part of an office (Haynes, 2007a). Haynes, (2008) proposed a framework that implied an occupant's work pattern influences an office's behavioural and physical environment. Both of these environments also affect office productivity. Haynes also suggested that from the layout of office space, comfort makes up the physical environment and social aspects such as interaction, privacy and collaboration constitute the behavioural environment of the office (Haynes, 2008a, Haynes, 2008b, Haynes, 2007b, Haynes, 2007a).

Comfort literature outlines its definition in a wide area, referring to various physical, social and personal aspects. The researcher acknowledges these influences on comfort and productivity from different areas of studies. However, this research's scope is limited to a sole focus on the physical environment and its quality.

The preliminary literature review outlined five physical factors that influence occupant productivity:

- **Thermal Comfort** (Fanger, 1970, de Dear et al., 1997, Tanabe et al., 2007, Djongyang et al., 2010, Lan et al., 2011)
- **Indoor Air Quality and Ventilation (Indoor Air Comfort)** (Vernon and Bedford, 1926, Wargocki et al., 2000, Fanger, 1988, Fisk et al., 2012)
- **Visual Comfort/ Lighting and Daylighting (Visual Comfort)** (Hopkinson et al., 1966, Alrubaih et al., 2013, L Edwards, 2000, Sivaji et al., 2013)
- **Noise and Acoustics (Acoustic Comfort)** (Sundstrom et al., 1994, Banbury and Berry, 2005, Mui and Wong, 2006)
- **Office Layout** (Brill et al., 1985, Laing et al., 1998, CABE, 2005, Haynes, 2009)

Preliminary literature outlines that these five factors have a substantial effect on occupant comfort and productivity. Literature also suggests that there are interdependencies and interactions between them. A change in Lux levels (Light) might influence occupant thermal comfort (Candas and Dufour, 2005). Similarly, daylighting affect thermal comfort. Windows absorb solar heat and increase the indoor temperature (Lyons et al., 2000). Temperature and indoor air quality also have interactions. As an increase in temperature tends to lower the occupant's perception of indoor air quality and vice-versa (De Dear and Brager, 2002), these interactions provide an opportunity to identify any more interactions and dependency. This research aims to identify more of these interactions (as stated in objective 4) by using response surface regression.

2.3 Thermal Comfort

Thermal comfort literature can be traced back to the early twentieth century (Dufton, 1929, Dufton, 1930). Early works highlight the initial steps towards understanding the effect of temperature of an indoor environment on human comfort and work (Winslow and Gagge, 1941, Gagge et al., 1941). (ASHRAE, 2004) defines comfort as the mental state of satisfaction with the thermal environment. It is a highly subjective state dependent on numerous physical, physiological and psychological factors (Lin and Deng, 2008), due to its dependence on highly independent and various categorical factors. These factors range from clothing, physical activity and seating, to location, posture and mental state (mood) (ASHRAE, 2005). Human factors that influence thermal comfort are age, gender, metabolism, local climate and geography (Quang et al., 2014, Cena and de Dear, 2001). Discomfort complaints calculate the thermal comfort of an indoor environment. Thus, thermal comfort is the cumulative response of occupants towards the thermal state, created by different physical parameters. Attaining thermal comfort for all the occupants in a building becomes an elaborate attempt.

Human response to thermal comfort is broadly described using three concepts; thermal sensation, thermal preference and thermal acceptability (Langevin et al., 2013). Thermal comfort and sensation are akin but differ in nature, i.e. thermal comfort is subjective, but the sensation is objective (Hensen, 1991). ASHRAE defines thermal sensation as an occupant's sensory perception of the immediate environment. It has a magnitude and a direction, described in a seven-point scale ranging from -3 (cold) to +3 (warm) (ASHRAE, 2010b). The literature outlines six primary factors that influence the thermal comfort of an occupant. These are air temperature, relative humidity, mean ambient temperature, clothing insulation and metabolic rate (Macpherson, 1973, Goldman, 1999, Berglund, 1977, Macpherson, 1962, Djongyang et al., 2010). Thermal preference of an occupant is the ideal thermal condition in an environment, whereas thermal acceptability is an occupant's level of approval of the thermal environment (Langevin et al., 2015, Langevin et al., 2013).

Regarding the measurement of thermal comfort, Fanger proposed a thermal comfort predictive model. It works on four physical parameters and two individual variables to define PMV (Predicted Mean Vote) (Lin and Deng, 2008, Fanger, 1984, Fanger, 1970). These are:

1. Air temperature

2. Air velocity
3. Mean radiant temperature
4. Relative humidity
5. Clothing insulation
6. Activity level

PMV helps to calculate a predicted percentage of dissatisfied occupants (PPD). PPD is used to predict the likely percentage of people who would feel on the scale of +3 (too warm), +2 (warm), -3 (too cold), -2 (cold) (Olesen and Parsons, 2002). It is based on heat balance theory and thermoregulation physiology (Charles, 2003). One of the drawbacks of this method is that it needs a climatic chamber so that data can be collected in it. It limits its application in some real-world scenarios.

De Dear, 2002, proposed another thermal comfort approach; it is based on the occupant's acceptability of the thermal environment. It outlines that the occupant's thermal acceptability of an environment affects occupant thermal comfort. It is highly dependent on human adaptation behaviour based on a physiological and psychological adaptation of the individual (De Dear and Brager, 1998, Brager and de Dear, 1998). This approach has been widely used in temperate climate conditions.

There are various thermal comfort standards developed across the globe, based on the above research (ASHRAE, 2005, ASHRAE, 2004, ASHRAE Standard, 1992, De Dear and Brager, 2002). These standards have been developed on the model and studies based in North America and Northern

Europe (Ogbonna and Harris, 2008). Also, they are applicable for uniform and static thermal conditions and do not count in various human-specific factors like age, local climatic conditions, gender, metabolic rates and thermal preferences and expectations (Han et al., 2007). Due to these limitations, there are hesitations and reluctance towards the global acknowledgement of discussing standards in the context of varied climatic conditions and a range of indoor actions in an office environment.

Thermal comfort has a high influence on occupant productivity. Occupants that report complaints of thermal discomfort have reported low productivity (Roelofsen, 2015, Lan et al., 2011, Akimoto et al., 2010, Tarantini et al., 2017, Lipczynska et al., 2018). Research indicates that temperature is crucial for occupant productivity. An office environment has a range of purposes, such as reading, typing and learning activities. Temperature from 18°c to 30°c has observed a diverse response to occupant productivity. In an office environment, 21°c - 25°c is observed to be the optimum temperature range for comfort. If the temperature goes above 25°c, every 1°c reports a 2% drop in productivity till 30°c (Kekäläinen et al., 2010, Seppänen and Fisk, 2006, Seppanen et al., 2003). Research evidence also suggests that productivity may not lie in the centre of the comfort range. The optimum temperature for productivity for different office tasks vary within the thermal comfort range (Tanabe et al., 2007). For instance, creative tasks may have a comfortable temperature range (21°c - 25°c), but intensity and speed required in/for an office work may need marginally cold temperature for optimal productivity

(Fisk, 2000a, Fisk, 2000b). It outlines that within the thermal comfort range, there are different micro range required to achieve maximum productivity. It emphasises the gap in the current practice of various design guidelines with a wide range of indoor parameters for occupant health. While an occupant comfort range is maintained, it is not necessary that occupants would be productive throughout the range of that temperature. There is a need to identify the productivity range within the comfort range of thermal comfort.

Literature suggests that a task-based, locally thermal environment helps to improve productivity (Zheng et al., 2009). Providing table fans, a local air conditioning unit and 'intelligent furniture' that controls its temperature have helped to improve the local thermal environment and improve occupant comfort and productivity (Zhao et al., 2017, Shahzad et al., 2018, Sekhar et al., 2005). Productivity also increases when occupants are provided with control of their thermal environment (Akimoto et al., 2010, Seppänen and Fisk, 2006). The sense of control improves the perception of their thermal environment. Thermal conditioning based on tasks has also reported improving the productivity of occupants (Akimoto et al., 2010, Seppanen et al., 2006, Zhang et al., 2010).

2.3.1 <u>Discussion</u>

The literature review above has outlined the background theories, significant factors affecting thermal comfort and the effect of thermal comfort on productivity and its complexity. The thermal comfort literature review can be traced for more than five decades (Macpherson, 1962). Thermal comfort can be divided into two aspects. The first aspect comprises of evident elements that define the thermal state of the environment. These elements include factors like temperature, relative humidity and air temperature. The second aspect includes the implicit human elements such as human perception, preference and their acceptance of the thermal state. These elements are a response to the thermal state. Based on literature and resource availability, this research would measure ambient temperature and relative humidity in the experiment. The first aspect influences the second aspect and its elements. The second aspect is subjective and depends on independent factors like age, metabolic rate, gender, and activity and clothing pattern. Literature also outlined two thermal comfort approaches. The first is a Fanger's model of rational approach and the second is De Dear's adaptive approach. The Fanger's model is specific in a thermal state but does not fully appreciate the second aspect's elements, such as human perception and acceptance. An adaptive approach is completely based on the second aspect of thermal comfort. The literature also outlines the various standards and guidelines on thermal comfort. These standards are a reasonable foundation for designing a building's heating, ventilation and air conditioning system.

The primary drivers of designing the thermal environment of a building should be based on its contextual climate conditions, the building's layout and orientation, material and occupant behaviour.

Field studies reviewed have also outlined that using an occupant survey, along with measurements of physical parameters of indoor environmental quality, is an effective method to measure a building's performance with regards to occupant comfort and productivity. Literature has also outlined those independent factors such as age, gender and activity pattern that influence thermal comfort. This research study uses the occupant survey to collect occupant response and sensors for physical measurement of temperature and relative humidity (Table 2.1).

Thermal Comfort			
Measurable parameters	**Instrument**	**Occupant Survey**	
Ambient temperature	Sensor	Sex	Occupant Response • Too cold • Cold • Satisfactory/neutral • Hot • Too hot
Relative humidity	Sensor	Age	

Table 2.1Thermal comfort – Parameters and Instrument

2.4 Indoor Air Quality and Ventilation (Indoor Air Comfort)

The quality of air in an indoor environment influences the indoor air comfort of occupants. Higher quality of indoor air leads to greater comfort and productivity (Ng et al., 2012, Fanger, 2000, Langer et al., 2016, Langer and Bekö, 2013, Wolkoff, 2018). Low air quality in existing buildings has reported, generating higher occupant dissatisfaction rate and various health issues in occupants (Bluyssen, 2014, Bluyssen, 2004, Bluyssen et al., 1996, Fisk et al., 2012, Fisk et al., 1993). More significant health issues reported are asthma, allergy symptoms and Sick Building Syndrome (SBS) (Wargocki, 2000, Jones, 1999, Silva et al., 2017). SBS is a significant problem in current building stock with poor air quality. Its symptoms are reported to be itchy, dry eyes as well as nose discomfort/irritation. Other symptoms are respiratory problems (primarily irritation), headache and mental fatigue (Hodgson, 2000). Indoor air quality depends on some of the independent physical parameters like contaminants in the air, humidity and temperature. These parameters depend on external climatic conditions, building material composition, air-conditioning system, internal layout design, heat and pollutant venting by machines or human actions. Complexity increases due to several interactions and deviations in these interdependent factors (Szczurek et al., 2015). The interaction between heat producing machines like high powered computers and bad internal layout design can lead to lower thermal comfort (Baker and Steemers, 2003).

Indoor air quality is maintained by changing the indoor air through the ventilation systems. It helps to reduce the air pollutants in the air and increases it's quality and occupant comfort. Carbon dioxide is the primary source of air pollutants in indoor air. It is measured in PPM (Particles Per Million) and removed using ventilation (Seppänen et al., 1999). Ventilation rate is one of the critical factors that affect indoor air quality, comfort and productivity. A higher ventilation rate leads to higher indoor air comfort and productivity, while a lower rate leads to SBS symptoms and reduces productivity (Ezzeldin and Rees, 2013, Frontczak et al., 2012, Frontczak and Wargocki, 2011, Wargocki, 2000). Research suggests that financial gains by increasing occupant comfort and productivity is several times more than the yearly expenditure of HVAC (Heating Ventilation Air-Conditioning) at a higher ventilation rate. In the U.S, if the ventilation rate in offices increases from 8 to 10l/s per person, 13 billion dollars yearly would be gained by higher levels of productivity and less health problem (Fisk et al., 2012). It is also recommended to use, efficient HVAC systems to reduce the environmental impact of higher ventilation rate.

There are three types of ventilation systems used in buildings, i.e. mechanically-ventilated buildings, naturally ventilated buildings and hybrid/mixed-ventilation system. Hybrid/mixed mode ventilation system uses both mechanical and natural ventilation process to ventilate the buildings. Research suggests that mixed/hybrid mode systems have higher air quality, which leads to higher comfort and productivity (Ezzeldin and Rees, 2013, Gou et al., 2014, De Vecchi et al., 2017). Despite these studies, ventilation mode should be selected by considering building typology, local climate and expected occupancy rate and impressions (Kim and de Dear, 2012).

Apart from carbon dioxide, chemical and Microbiological Volatile Organic Compounds (VOCs/MVOCs) affect indoor air quality and comfort. High levels of VOC are associated with bad odour and irritant characteristics with low-level toxic properties (Panagiotaras et al., 2013, Wolkoff, 2013). There are several industry guidelines on indoor air quality standards that underline the recommended level of contaminants in the air to maintain a healthy indoor environment (WHO, 2006, ASHRAE Standard, 1989). VOC has both chemical and physical properties that make it complicated to design measures and suggest values for analysis (Teichman et al., 2015). Fanger proposed Decipol and Olf measure contaminants and their sources (Fanger, 1988). The emission rate of air pollution is Olf, which is based on the emission rate of one occupant. Decipol is based on the rate of pollution by one occupant while ventilation operates at 10l/s of fresh air. It is used to exhibit air quality (Kosonen and Tan, 2004, Fanger, 1988). High level of VOC in the air is associated with new furniture, paints and specific materials (Association, 2011). Hence, the new buildings are found to have higher levels of VOC.

2.4.1 <u>Discussion</u>

The literature review of indoor air quality can be summarised in three threads. The first thread focuses on the constituents on indoor air, outlining the effect of carbon dioxide, air temperature and contaminants on the quality of air. Main components that can be used to improve air quality are carbon dioxide and VOC. The second thread focuses on improving air quality using ventilation. It presents the research trends on ventilation from the early twentieth century (Vernon and Bedford, 1930). Ventilation research progressed towards defining standards for building ventilation (ASHRAE Standard, 1989) and identifying the ventilation requirement of different types of buildings and indoor activities within a building (Fisk et al., 2012, Zhang et al., 2010). Third thread focuses on the effect of air quality on occupant health and productivity. Occupant's health is the primary motivation for indoor air research. Several health problems related to Building Related Illness (BRI), Sick Building Syndrome (SBS), and Occupational Asthma (OA) were documented in the late twentieth century (Jones, 1999, Wargocki, 2000).

All of the threads are highly interrelated and need to be inferred in order to create a comprehensive understanding of indoor air quality and its effect on occupant health and productivity.

This research focuses on measuring carbon dioxide, VOC, and collecting the occupant response in the experiment (Table - 2.2).

Indoor Air Quality		
Measurable parameters	**Instrument**	**Occupant Survey**
Carbon Dioxide	Sensor	Occupants' response to the indoor air quality
Indoor pollutant level (Volatile Organic Compound)	Sensor	

Table - 2.2 - Indoor Air Quality - Parameters and Instrument

2.5 Lighting and Daylighting (Visual Comfort)

Visual comfort also influences occupant comfort and satisfaction within an indoor environment (Frontczak and Wargocki, 2011). Visual comfort depends on the nature and level of lighting - both daylight and artificial light. Daylight influences our biological clock. It is set for millions of years based on the sun's movement (sunrise and sunset). It controls our physiology and productivity (Aries, 2005). Daylight is advised to be the best source of light with excellent colour for human health and comfort. It has a positive influence on occupant mood, performance and mental attitude (Li and Lam, 2001, Schaffner et al., 2018, Beute and de Kort, 2018). As office employee spends most of their time indoors (Bernstein et al., 2008), office environments depend greatly on artificial lighting, due to numerous circumstances like building design, orientation, and availability of sunlight, due to clouds or windows. Due to this dependency on artificial lighting, buildings worldwide use about 40% of the world's annual usage (Omer, 2008). In the UK, research suggests that lighting has the most significant share (33%) in total average utilisation (CIBSE, 2015) (See Figure 2.1). In the US (2002 data), around US$40 billion per year is spent on electricity for lighting. About one-third of this expenditure is spent on lighting consumption by American workers, taking US$5.3 trillion in salaries and producing goods and services worth US$9.2 trillion (Steffy, 2002). Indoor lighting has a one-third share in global office electricity consumption. These facts make it is one of the significant contributors to global carbon emissions (Busch et al., 1993).

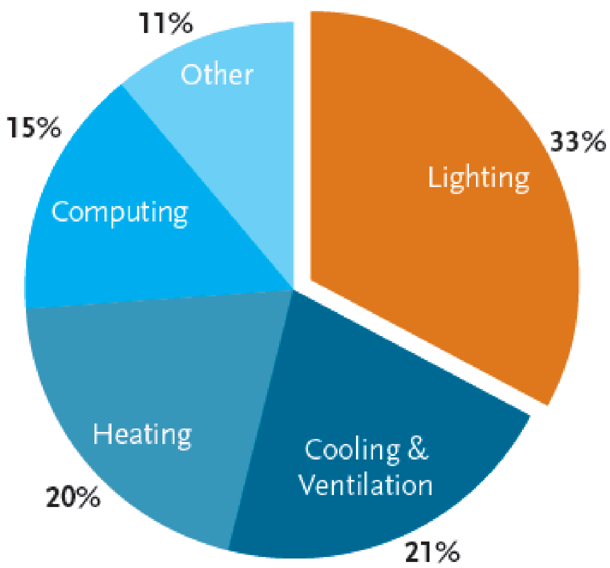


Figure 2.1 - Electricity usage (UK) (CIBSE, 2015)

Research suggests that companies gain long-term profit by higher occupant productivity and lower electricity cost by investing in daylight inclusivity in the workplace design (Fay et al., 2002, Yang and Nam, 2010, Lim et al., 2017). Daylight inclusion in workplace design has led to an increase in attendance and a decrease in occupant complaints in offices (Romm and Browning, 1994). Humans prefer natural light when compared to artificial light (Elzeyadi, 2011, Kong et al., 2018). Preference can be divided into three categories; psychological, physiological and physical. Artificial lighting covers a wide range of the colour spectrum that covers the range of sunlight and daylight. The main reasons are psychological and physiological factors. Human performance is highly dependent on parameters such as luminance contrast, retinal illumination, retinal image quality and visual size (Boyce et al., 2003). The visual and circadian system is influenced by natural light (Rea et al., 2002). It also influences melatonin hormone, which regulates the body's clock that helps to maintain the sleep and alertness pattern in the body. It contributes in maintaining alertness and focus during office hours (Nagy et al., 1995). Both daylight and natural light refer to the light provided by direct or indirect presence due to sunlight.

There are many ways to incorporate daylighting into workplace design. One of the widely used is to incorporate windows to maximise daylight in the workspace. Occupants also prefer workplaces with windows and report that they help in improving the productivity of office tasks (Cuttle, 1983, Lottrup et al., 2015, Haans, 2014). Outside views of surrounding green areas and nature also lead to a positive impact on occupant productivity (Bright, 2012, Grinde and Patil, 2009, Heerwagen, 2003). There is evidence of occupants' preference for natural light and windows. However, various factors need to be accounted for, while designing windows for a workplace. Excessive daylight or other light causes 'glare'. It leads to strain in the eye and temporarily reduces the visual capability of the subject (human) experiencing it (Słomiński and Krupiński, 2018). These factors include outdoor lighting levels, required indoor lighting levels, outside sky illuminance and position of the sun (Ne'Eman, 1970, Mansfield, 2018). Occupant surveys also indicate that universally, they prefer to have access to sunlight; desired size and locations of the windows may vary depending on the light requirement, size, layout and position of the desk (Butler and Biner, 1989, Wotton, 1982). In high-rise buildings, providing large windows on the south side (low sun path) leads to higher usage of blinds, compared to the north side of the building (Rubin et al., 1978). In summary, occupants prefer daylight at the workplace; however, window size and location should be determined based on various factors like lighting requirement of the space, layout and orientation of the building, its location and availability of daylight.

Daylighting design is a method to incorporate daylight into the lighting design of a space. It looked at the daylight availability and required levels of light using different elements, such as a window, skylight and reflector glasses (Guzowski, 2000, Manning, 2006, Farkas, 1985, Kittler et al., 1992). Illuminance from natural sources is calculated by the Daylight Factor (DF). This represents the percentage of daylight in the overall lighting of the space (measured at overcast conditions), which is based on three factors; Sky Component (SC), External Reflected Component (ERC) and Internal Reflected Component (IRC) (Wong, 2017, Hopkinson et al., 1966, Fontoynont, 2014). The literature recommends 1.5-2.5% DF for regular tasks like filling work, general reading and meetings. Tasks that require reading, writing and machine work for long hours need 2.5% - 4% DF. Mentally straining, challenging tasks that require high focus and attention to detail, such as, draughting, fine hand or machine work, writing reports and document inspection need 4% - 8% DF (Stein et al., 1992, Reinhart et al., 2006). These percentages represent the preferred factor of daylight in the overall illuminance (Lux) of the space. Designers need to be mindful while designing the overall illuminance of the space. A higher level of illuminance levels leads to glare that results in visual discomfort.

Similarly, lower illuminance levels also lead to melatonin hormone secretion that affects alertness, performance and visual discomfort. Illuminance is the total light's incidence on a surface, measured as Lux (lx) (DiLaura et al., 2011, Hopkinson, 1963). Visual discomfort leads to lower productivity and well-being (Van Den Wymelenberg and Inanici, 2014, Kong et al., 2018). Maintaining conducive illuminance levels for healthy and productive workspace is necessary. Different types of tasks require different illuminance levels. For regular office work such as file work, general reading and meetings, the minimum required is 100 Lux, while the recommended average is 200 Lux. For office work that requires some detail work such as report writing and reading, 200 - 300 Lux range is recommended. For detailed work for the long duration of time, such as draughting, fine hand or machine work, the recommended range is 200-500 Lux (Rea, 2000).

Based on the above literature review, we can conclude that the lighting design of a workplace should use both indoor (artificial) lighting and daylight to create a conducive lighting environment for the occupants. It should look at contextual factors such as:

1. Light requirements based on tasks and working hours
2. Location, orientation and height of the workplace
3. Occupant requirement and preference
4. Availability of daylight

Along with the above factors, designers should aim to reduce the lighting energy consumption by using various daylighting strategies (Chang and Mahdavi, 2002, Doulos et al., 2005). Managing light systems by using different light sensors and relays can help to reduce electricity consumption. This system can be used in two ways:

- Maximising daylight usage: A building's electricity usage can be reduced by using operational façade elements to use daylight in the building efficiently. It involves the use of sensors to automatically open and close the façade elements by measuring and sensing the outdoor illuminance concerning required indoor illuminance.

- Reducing artificial light usage: Building's electricity usage can be reduced by using various movement/occupancy sensors to switch off when occupants leave the building.

2.5.1 Discussion

The literature review of lighting and daylighting has outlined the fundamentals of lighting, its importance in improving occupant productivity and ideal range based on industry standards. It also outlined various ways to incorporate daylighting into the lighting design of a workspace.

The lighting of a workplace should be designed using several factors. These include lighting, colour and contrast levels that are comfortable for the human eye. Lighting design should also consider the specific lux level requirements for different types of tasks. A combination of lighting system should be designed that uses both artificial and daylighting to create a sustainable and efficient approach that provides a conducive lighting environment to improve occupant comfort and productivity.

This research focuses on measuring illuminance levels (Lux), daylight access and their influence on occupant comfort and productivity (Table - 2.3).

Lighting and Daylighting		
Measurable parameters	**Instrument**	**Occupant Survey**
Illuminance level (Ambient)	Lighting Sensor	Occupants' response to indoor lighting
Daylight access	Location of the	

	occupant • Exterior wall • Interior wall • Exterior window • Interior window	

Table - 2.3 - Lighting and Daylighting - Parameters and Instrument

2.6 Noise and Acoustic (Acoustic Comfort)

Hearing ability is an essential human sense. It has been a part of human's survival kit for generations. It is hard-wired to the brain to produce a quick response. In the case of unwanted sound or noise, the body has psychological responses like annoyance, irritation and anger (Berglund et al., 1996, Stansfeld and Matheson, 2003). Sound is measured in decibels (dB), sound pressure levels (SWL) and sound power levels (SPL). High noise and its psychological and physiological consequences have been highlighted by several research works (Lee and Fleming, 2002, Ising and Kruppa, 2004, Shapiro and Suter, 1991, Smith et al., 2017). Adverse effects of noise lead to hearing impairment sleep disturbances, cardiovascular disturbances, mental disorders, impaired task performance and negative social behaviour (Gunderson et al., 1997, Evans and Lepore, 1993, Korte and Grant, 1980, Fuks et al., 2017, Bronzaft, 2000, Palmer, 2018). These problems, combined with environmental requirements of a workplace, demand that acoustic design is highly significant in the workplace. Occupants require a comfortable acoustic environment to work efficiently. Acoustic discomfort in the office environment can lead to lower productivity and higher chances of detrimental effects on the psychology and physiology of occupants (Sundstrom et al., 1994, Vischer, 2007, Chang et al., 2003, Eriksson et al., 2018, Neitzel et al., 2018). Workspaces have two types of sources - internal sound source and external sound source. Internal sound sources include office equipment and occupant noise (conversation). External sounds can vary from traffic (road, rail, air), construction and public events (Banbury and Berry, 2005, Ayr et al., 2003, Fuks et al., 2017, Bielefeld, 2018). Both external and internal noises have a detrimental effect on occupant performance. Studies suggest that constant external noises from transport and construction induce stress and blood pressure problems (Passchier-Vermeer and Passchier, 2000, Bluyssen et al., 2011).

Similarly, internal noise such as air conditioners, fax machines, printer and telephone sounds leads to irritation and annoyance; a continuous state of annoyance leads to stress and high blood pressure problems (Ayr et al., 2003). In a research experiment, occupants were exposed to various background noises. Results outlined that occupants responded with a drop in performance by 65% in 'memory for prose' tasks, and 99% participated people responded that background noise (office noise) impaired their focus (Banbury and Berry, 2005). Overall comfort and productivity are an outcome of achieving various types of comfort. For instance, an occupant cannot be comfortable if he/she is thermally comfortable, but there are different types of background noises in the environment. Research suggests that acoustic sensation has a similar effect as thermal sensation. Variation in 2.6 dB of sound and the 1°c temperature has a similar effect on productivity (Pellerin and Candas, 2004). So, indoor environment quality parameters have a combined effect on occupant productivity.

Building envelope material can be used for keeping external noise in control. The internal arrangement, wall material and office layout can be used to manage internal noise in a workplace environment. Open plan design has been associated with low motivation and fatigue in employees (Jahncke and Halin, 2012). As open-plan offices do not provide any barrier between meeting areas/ conversation areas and work areas, employees have reported privacy and disturbances due to various office noises such as conversation, telephones and printers (Toftum et al., 2012). Sound masking is one of the strategies used to reduce the variation in sound levels, due to internal noises. It involves maintaining an essential background sound using office speakers that work around the level of typical air-conditioned offices (45dB – 60 dB). It helps to reduce the acoustical spike in the environment and mask regular conversations to provide a smoother acoustic experience (Mui and Wong, 2006). White noise is used to maintain the basic sound levels in the office.

The minimum unoccupied sound level of an open plan area is 45dB and cellular/private offices are 40dB. The standards recommend maintaining a 40-50dB sound level in the workplace environment (Field, 2008). Internal noise can be controlled by the following:

1. Sound masking (discussed above).
2. Reducing the noise from sources like printers, air conditioning units, etc.
3. Dividing the areas based on expected sound levels and space requirements.
4. Using sound absorbent materials in the higher sound-producing areas like a printer room, café, meeting rooms and social areas.
5. Soundproofing the sound sensitive areas that require certain sound levels to be maintained. However, any sound producing source should be kept out of this area.

2.6.1 Discussion

The above literature review has outlined the importance of sound levels in occupant comfort and productivity. The sound comfort of an occupant depends on the internal and external sounds. Managing internal and external sound using various strategies can help to contribute to improving occupant comfort and productivity. For internal noise, the acoustic design should incorporate the nature of tasks in the office and divide the areas based on the expected level of noise. Use of noise absorption material in noisy areas and soundproofing for low noise areas can be used to improve the acoustic environment of a workplace.

This research measures sound levels (dB) and occupant response in a longitudinal experiment to determine the effect of sound levels on occupant comfort and productivity (Table - 2.4).

Noise and Acoustics		
Measurable parameters	**Instrument**	**Occupant Survey**
Indoor sound level	Decibel sensor	Occupants' response to the noise level in the office

Table - 2.4 Noise and Acoustics - Parameters and Instrument

2.7 Office Layout

As highlighted in the previous section, the office layout plays a vital role in the acoustic design of the workplace. It also influences overall occupant comfort, and productivity in several ways. The office layout is responsible for creating the seating design that defines the working pattern of employees, their proximity to each other, social/interaction opportunities (areas) and privacy (Haynes, 2008b, Lee, 2010). Physical environment (layout, appearance) of a workplace influences employee satisfaction. It affects an organisation's retention, recruitment, and productivity (Wheeler and Almeida, 2006). This literature outlines two types of office layout; open plan and cellular offices (Haynes, 2008b). There are sub-versions of these offices:

- Open plan
  - Shared open plan space
- Cellular
  - Individual room

- Shared room
- Cubicle

In order to understand the organisation's work processes, the pattern is crucial when designing an office layout. Research indicates that the office layout designed without considering the organisation's work process has led to a loss in organisational productivity (Laing et al., 1998). Different offices have different work processes based on organisational structure, sector and corporate strategy. There are four types of office layout structuring (Laing et al., 1998).

- Cell - It is used by organisations that have a majority of individual work that doesn't require any interaction.
- Den - It is used by organisations which require a high level of group work and a low level of individual tasks.
- Hive - It is used by organisations that require both cellular and open plan offices due to similar requirements for team-based and individual tasks.
- Club – It is similar to the Hive. However, the club uses cellular offices along with hot desking facilities. It provides a balance between private spaces and group spaces. Organisations that have irregular occupant patterns use this type of office layout.

These office layout structures present a wide variety of options for different types of organisations. A range of studies has indicated that, when compared to a cellular office, open plan offices are associated with lower productivity and higher complaints (Lee, 2010, Jahncke and Halin, 2012, Toftum et al., 2012, Kim and de Dear, 2013, Shahzad et al., 2016, De Been and Beijer, 2014, Otterbring et al., 2018, Borin and Monteiro, 2018).

The central point of designing an office layout is to identify different types of tasks in the office environment and identifying features that will help to improve the organisation's workflow and productivity (Stone, 2001). Office layout can be used to create flexible design components that provide privacy and distraction-free spaces along with interactive and social spaces. An organisation needs both types of space. The absence of interaction and the presence of distraction have a negative impact on occupant productivity (Haynes, 2007a). The office layout influences the non-physical aspects of an organisation's operations. Interactive and informal spaces shape the culture of the organisation; while the design features and artefacts have a different effect depending on the task. Vibrant colours and highly interactive spaces improve creativity and knowledge sharing in an organisation (Kallio et al., 2015).

These micro design aspects can be investigated for comparison between different types of organisation, their task types and their culture. However, this research would focus on the broader effect on office layout on productivity.

2.7.1 Discussion

The literature review on office layout has highlighted that different types can influence occupant productivity and office efficiency. It also highlights that open-plan offices have a negative influence on occupant comfort and productivity. The cellular room (individual, shared room) is associated with higher comfort and productivity. While designing an office, the layout should be designed based on several factors. These include office work processes, tasks, sound level requirements and privacy and interaction requirement of the occupants. This research will investigate the effect of office layout (open plan and cellular) on occupant comfort and productivity (Table 2.5).

Office Layout	
Analysis	**Occupant Survey**
Office layout a. Individual room b. Shared room c. Cubicle d. Open plan e. Shared open plan space	Occupants' response to office layout

Table 2.5 - Office Layout - Parameters and Instrument

2.8 Qatar Context

The research in this study took place in Doha, Qatar. Qatar is part of the GCC (Gulf Cooperation Council) group of countries. There are six GCC countries. These are Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates. Their economies have experienced a 50% increase in the last three decades (Bank, 2014). It includes an increase in Foreign Direct Investment (FDI) and exports (Almfraji et al., 2014). There is an increase in multinational companies becoming established and investing in these countries. All of the GCC countries have been racing to modernise their cities and nations, with Doha being one of the top destinations for FDI (Foreign Direct Investment) and international companies' investment. The majority of commercial activities in Qatar are concentrated in Doha. Historically, Doha was a fishing town and has experienced modernisation since the 1970s. However, the major push in the modernisation came in the late 1990s after the discovery of major gas reserves in Qatar (Economides and Wood, 2009). Since this discovery, Qatar has seen a consistent rise in economic growth. It has also led to major commercial and residential development in Doha. The 2006 Asian games in Doha has resulted in about 180 towers in Doha's West Bay by 2009. In 2010, an additional 500,000 m^2 was required in Doha and led to further development (Mahgoub and Abbara, 2012). It indicates that significant sports events lead to building and infrastructure development at the city and national level.

Qatar is preparing for the FIFA World cup 2022. This preparation is worth US$20 Billion investment in transport infrastructure, stadiums, commercial and residential development (Millward, 2017). Hosting mega sports event like world cup leads to boost in tourism, national sporting interest, sociocultural and infrastructural and global exposure and interest (Fredline et al., 2003, Lee et al., 2005, Rogerson, 2009, Al-Emadi et al., 2017). Hosting such events also produce a boost in international interest from multinational companies to invest and develop business (Karadakis and Kaplanidou, 2012, Deccio and Baloglu, 2002, Jones, 2001). It has led to significant development in commercial buildings. While the stock of commercial buildings and occupants is increasing, there is a need to focus on the comfort and productivity of these occupants. Qatar has GSAS (Global Sustainability Assessment System) building rating system. Similar to other green building rating system, it primarily focuses on occupant comfort and energy efficiency of the building (GSAS/QSAS, 2012). It does not focus on occupant productivity in commercial buildings. There is a gap in knowledge and focus.

The local weather also motivates investigating the effect of indoor environment quality on occupant comfort and productivity. People usually spend 95% of the day indoors (home, office, public buildings) (Klepeis et al., 2001). This figure reaches 98% in summer due to temperature reaching up to 50 °c (Saraga et al., 2017). Extreme weather conditions in Doha have also led to the newly built environment to be tightly sealed and air-conditioned buildings with a glass envelope. Residents are spending almost all time indoors in a sealed environment that has a significant impact on their comfort, health and productivity. There are few studies on the indoor air quality in the middle east region in the area of residential and educational buildings (Jaffal et al., 1997, Jaradat et al., 2004, Yassin et al., 2012, Yeatts et al., 2012). These studies indicate the importance of indoor air quality in the desert climate and its impact on occupant health and comfort. Multiple studies on thermal comfort, visual comfort and acoustic comfort in a range of building types in the Middle East region indicate that they have impact on occupant health and comfort (Indraganti and Boussaa, 2018, Attia and Carlucci, 2015, Alzubaidi et al., 2013, Sehar et al., 2017, Al Touma and Ouahrani, 2018, Indraganti and Boussaa, 2017, Salama and Courtney, 2013). Doha is also one of the few cities in the world with people coming from a range of countries. Doha is one of the top cities with diverse residents and workforce (Salama, 2013). As discussed before, gender, ethnicity, age influences the individual's comfort level (Roelofsen, 2002, Brager and Baker, 2009, Kim et al., 2013). So, the diverse population also provides an excellent opportunity to investigate the effect of indoor environment quality on occupant comfort with a sample of diverse ethnicity.

To conclude, the high level of commercial development, harsh climatic condition and diverse resident and workforce provides a unique opportunity to investigate the impact of indoor environment quality on occupant productivity. It will help to achieve results that can be used in other major cities with a diverse population in the Middle-east region.

2.9 Summary of the Chapter

This chapter has presented the literature reviewed to understand the different IEQ factors and their parameters (Table 2.6). It also explains the theoretical background of each factor, its effect on occupant comfort and productivity. Each section also highlights the parameter/s to be investigated under each IEQ factor. Below is the table of parameters listed against each type of IEQ factors and associated comfort (Table 2.8).

IEQ factor	IEQ parameter
Thermal comfort	Temperature (Indoor, Outdoor) Relative Humidity (Indoor, Outdoor)
Indoor Air Quality (Indoor Air Comfort)	Carbon Dioxide
	VOC (Volatile Organic Compound)
Lighting and Daylighting (Visual Comfort)	Lux levels
Noise and Acoustics (Acoustic Comfort)	dB levels
Office Layout	Open Plan or Cellular

Table 2.6 IEQ Factors and their parameters

The next chapter presents the research methodology of the current research, outlining the research approach, philosophy and strategies used in the current study.

3 Research Methodology

The gap in the knowledge of indoor environmental quality and occupant productivity outlining the factors that affect occupant productivity has been identified. This chapter will now outline the next step of this research. It will help to develop an appropriate research methodology for this study. Research design should help to achieve the set aim and objectives of this study. Hence, this chapter would look into various research tools and methods that would help to achieve the desired results. It examines research design, tools and technology used in the research area of indoor environmental quality. There are ten sections in this chapter. The first section introduces the research methodology approach selected for the current research study. The second part presents the research philosophy, highlighting the Ontology, Epistemology and Axiology stance of the research study. The third part describes the research approach of the study, explaining the deductive and inductive approach chosen by the researcher. The fourth section discusses various research strategies that can be used in a research study. It describes a post-occupancy evaluation strategy and its implementation. The fifth section presents the research choice of the quantitative and qualitative method of research; the sixth section outlines the time horizon of the study. The following section describes the research phases in the study. It also discusses various activities undertaken in each phase. The ninth section presents the risk mitigation strategy of the study.

3.1 Introduction

The research methodology is a method to solve a research problem systematically. It lays down the structure and procedure for the research process and provides a path from research aim to the results and findings. The research design of a study helps to focus on research questions and problems by using appropriate research tools and strategies. Choosing an appropriate research methodology is critical in achieving reliable and robust results and findings (Yin, 2017). This research study refers to "research onion" research methodology model (Figure 3.2). It represents an overall methodology as several onion layers in dimensions such as research philosophies, approaches, strategies, choices, and time horizons, and techniques (Saunders et al., 2011). All of these layers need to be addressed or "peeled away" to solve the research problem. Appropriate methodology selection is essential to achieve a concise and reliable result. It is worth noting that research methodology selection requires an understanding of research philosophy.

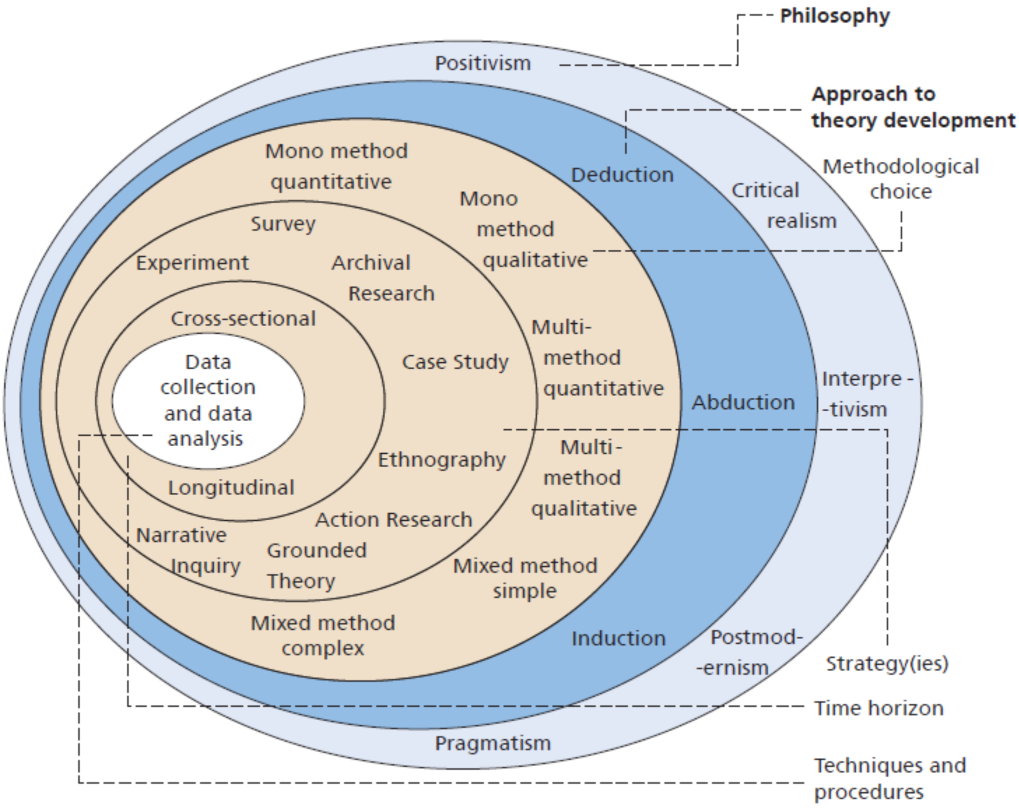


Figure - 3.1 - Research Onion (Saunders et al., 2019))

3.2 Research Philosophy

Research philosophy outlines the development and the nature of knowledge. It helps to establish a global view to inform the overall methodology and research process of the study (Corbin et al., 2014). It highlights how the researcher views the world and reality (Saunders et al., 2011). Research Philosophy has three significant ways of thinking; Ontology, Epistemology and Axiology (Sexton, 2003).

Epistemology deals with general assumptions about how we acquire and accept knowledge about the world. It is represented by positivism, critical realism, Interpretivism, Postmodernism and Pragmatism (Saunders et al., 2011, Saunders et al., 2019). Positivism is a search for cause-effect relationships by the rational approach. It involves observation of neutrally and objectively. It uses large samples of quantitative data and statistical testing. Critical realism follows epistemological relativism. It emphasises on historically situated facts and social constructs and uses them as a causal explanation. Critical realists see reality as external and independent, but not directly accessible through observation and knowledge (Reed, 2005). Interpretivism is a search for explanations of human actions (Sexton, 2003). It focuses on researching individuals, rather than objects. It adopts an empathic stance to understand the social world and give meaning to their point of view. The data collection and analysis involves qualitative data and in-depth investigations with small samples. Postmodernism is based on identifying truth and knowledge using dominant ideologies in particular context. It believes that there is absolute 'truth' and 'right', but they are decided collectively based on the social ideologies (Foucault, 2018). Pragmatism philosophy uses both objectivism and subjectivism. It postulates the use of fact and values, accurate and rigorous knowledge. The pragmatist approach to reality is that it is a practical effect of ideas and knowledge (Kelemen and Rumens, 2008).

This research study aims to investigate the effect of indoor environment quality factors on occupant productivity. It involves analysing the ideal range of various indoor environmental conditions such as temperature, light and sound levels. The study requires data collection of indoor environmental quality factors, followed by statistical analysis of the collected data. It investigates the cause-effect relationship between indoor environmental quality and occupant's comfort and productivity. It can be stated that this study would take a positivist stance.

The ontology outlines what we make about the nature of reality. It consists of two main aspects; objectivism and subjectivism. Objectivism highlights a position where social entities exist in a reality that is external to the social actors concerned with their existence. Subjectivism states that the perceptions and actions of social actors handle the creation of social phenomena (Saunders et al., 2011). This research study deals with tangible, measurable parameters of indoor environment physical factors; thus, it deals with objective data, and it can be stated that this research takes objectivism position in ontological stance.

Axiology studies the researcher's judgement about value. It is the science of inquiry into human values. It concerns about researcher's axiological skill to demonstrate "value-free" and "value-laden" attitude towards the research. Value-free research is value-free and objective, whereas value-biased research is value-laden and subjective (Sexton, 2003, Bazewicz, 2000). The researcher would be external to the experiment. The researcher believes that he would place himself as "value-free".

3.3 Research Approaches

Research approaches are of three types; inductive, abductive and deductive. Deductive reasoning approach works from general to specific. It is informally called a "top-down" approach. It usually starts with a theory about the topic of interest and is then narrowed down to the most specific hypothesis that can be tested. Furthermore, it is narrowed down into observations to address the hypothesis, which leads to hypothesis testing with accurate data; either confirmed or not. Abductive approach is based on incomplete or vague facts/puzzles, observations. It aims to best predict the result or hypothesis based on these incomplete observations. Inductive reasoning works in another way. It moves from specific observations to broader generalisations and theories. It is informally called as "bottom-up" approach, starting with precise observations and measures and progressing to identify patterns, formulating a tentative hypothesis. This hypothesis is explored to develop conclusions (Robson, 2002, Lewis et al., 2007).

This research study aims to develop a model (set of equations) that seeks to define a statistical relationship between different IEQ factors and occupant productivity. The research study proposes to measure indoor environmental quality factors and capture occupant response to those indoor environment quality factors. The research study uses the response surface analysis to establish the patterns and relationships between different indoor environmental quality factors and occupant response. It starts with observations and measurements to identify the patterns and develop a relationship model based on the experiment. Therefore, this research study will have an inductive research approach.

3.4 Research Choice

There are many research options available for a research study. Broadly, there are two types of method; quantitative and qualitative. A qualitative method is principally used in three scenarios. First, when there is a need to explore an issue or a specific subject area; Secondly, to investigate and understand an individual's opinion and preferences to develop a theory and hypothesis. Thirdly, to develop theories based on an individual's behavioural patterns and preferences (Creswell and Creswell, 2017). This method uses interviews and group studies to collect data (Lewis, 2015). Mono or multiple qualitative strategies can conduct research. Quantitative method is used to investigate existing principles, theories and pattern and test their reliability and level of precision (Yin, 2009) and is often used in hypothesis testing. Similar to the qualitative method, quantitative research can be conducted using both single and multi-research methods. Also, research design can be based on both quantitative and qualitative research design. This research follows positivist philosophy with an objective view to the reality. It is also value free and external to the experiment. It follows an inductive approach to create a hypothesis on the relationship between indoor environmental quality and occupant productivity. Based, on the above layers, this research study is going to use a quantitative method to define the IEQ and productivity relationship model in the research and development phase.

This research aims to establish the relationship between indoor environmental quality and occupant productivity using primary data. The nature of the study would be explanatory.

3.5 Research Strategies

There are various types of research strategies such as experiment, survey, action research, and grounded theory, archival research and case study (Lewis et al., 2007). The choice depends on the research questions(s) and objectives, existing knowledge, time and research resources and area of research. This study has taken the inductive approach along with quantitative research design. The data collection strategy would be influenced by choice of the research method. This research study would consist of primary data collection that enables to establish the correlation between indoor environmental quality and occupant's comfort and productivity. It is necessary to briefly look at various research choices to choose the appropriate research strategy.

3.5.1 Experimental Research

Experimental research usually means to conduct a research process that examines the results of an experiment. The experiment can be based on a quantitative and qualitative method. It is often conducted in a controlled environment to ensure the accuracy of the result. The purpose of the experiment is to define the change or probability of change in the dependent variable by the independent variable (Saunders et al., 2012, Hakim, 2012).

3.5.2 Survey

It is used for research studies that require the collection of opinion or statistics from people. It allows collecting quantitative data quickly on email, websites or electronic forms. It is highly applicable in identifying a particular relationship between variables and to produce models of these relationships. This method allows a streamlined data collection but also limits the depth of data collected. Hence, it is the most appropriate for quantitative analysis (Rossi et al., 2013).

3.5.3 Archival Research

It involves using records and documents as the principal source of data (secondary data) to investigate. It is usually applicable in defining patterns of people behaviour or day to day activity (Hakim, 2012). It involves the collection of secondary data. Hence it is not applicable in this research study.

3.5.4 Case Study

The case study method is used to study a case focused on a particular topic within a context (Yin, 2017). It helps to study and understand the why, how and what questions. It is highly applicable in the exploratory studies. It usually includes the interviews, observations and documentary analysis for the research study (Eisenhardt and Graebner, 2007). It is not applicable in this research study because of the nature of the research study. It involves describing the relationship between different variables, and case study is not suitable for the required aim and objectives.

3.5.5 Ethnography

It is a method used to study in groups. It is primarily focused to gain insights about a topic of research/interest. It is used primarily in the exploratory research to create a better understanding of a problem and potential solutions and is primarily qualitative (Hammersley and Atkinson, 2007). This research study requires a quantitative approach and ethnography is not suitable for this study.

3.5.6 Action Research

Action research is an iterative process that enables to solve a problem using a collaborative and participative approach (Reason and Bradbury, 2001). It involves the researcher to be involved in the iterative process of planning, taking action, evaluating and diagnosing while being close to the research topic/topic of interest (Coghlan, 2019). It is repeated for three cycles to improve the solution of the presented problem. This research study defines the relationship pattern between indoor environmental quality and occupant productivity without disturbing or being part of the environment. Hence, action research is not an appropriate research strategy for this study.

3.5.7 Grounded Theory

Grounded theory is a methodological approach that uses different methods of inquiry and research process to attain the result. It was developed to analyse, interpret the social constructs and actors to understand the experience in specific situations (Charmaz, 2006, Glaser and Strauss, 1967). It is used for the development of theoretical explanations of social interactions in a range of contexts. The process involves reorganisation of data, identifying relationships between different categories and then analyse the identified categories to develop theories(Reichertz, 2007). It involves intensive social theoretical analysis and its reflective. This research study involves the development of a relationship between indoor environmental quality and occupant productivity. It does not require a reflective process and analysis; hence it is not appropriate for this research study.

Based on analysing different research choices, use of experiment with a survey would be the most appropriate research instrument for this research study. It requires a non-intrusive experiment by setting up sensors for collecting data on indoor environment quality parameters along with mapping occupant's response to the indoor environment. The next section would outline the investigation and development of these research strategies.

3.5.8 Experiment Design

Based on the above analysis, this section aims to define the appropriate research strategy for the study.

The literature review has listed several physical indoor environmental quality factors in the workplace that influence occupant productivity. Studies in the area of indoor environment quality have used several data collection methods to map occupant discomfort and its effect on productivity, along with the physical parameters of indoor environmental factors. One of the methods is called Post Occupancy Evaluation (POE). It is used to identify any performance shortcomings in the building's operation by collecting occupant response against physical parameter measurement. Data collected in this method is used to map several relationships and trends. It has been used to identify the correlation between occupant comfort and indoor environment quality parameters, building energy consumption and operational performance (Göçer et al., 2015, Preiser et al., 2015). POE can be conducted by measuring the physical parameters of the environment, bill and building consumption metrics, and occupant response using surveys (Ozturk et al., 2012). This research study would use occupant response using an online survey and measurement of physical parameters of the indoor environment to define the relationship between IEQ and occupant productivity.

3.5.8.1 Occupant Response (Subjective Evaluation)

A wide range of research studies have used occupant response (survey, interviews) to examine any problem or performance shortcomings of a building (Hassanain, 2007, Deuble and de Dear, 2012, Preiser, 1995, Nicol and Roaf, 2005, Kong et al., 2018, Rasheed and Byrd, 2018). Surveys are used to collect data remotely by sending questionnaires using a paper-based method or email. They are used for quantitative studies. Interviews are used in a more in-depth study with a qualitative focus on the research (Bryman, 2016). This research study aims to outline the relationship between indoor environmental quality and occupant productivity and is a quantitative study; hence it will use surveys as a method of data collection.

A comprehensive review of surveys used for building performance and occupant comforts outline a list of survey instruments used in the academia and industry (Dykes and Baird, 2013).

- ASHRAE RP-884 (De Dear and Brager, 1998)
- CBE Survey (Centre for the Built Environment) (Zagreus et al., 2004)
- OPN (Office Productivity Network) (Oseland, 2004)
- BOSTI (Buffalo Organisation for Social and Technological Innovation) - (Brill et al., 1985)
- BUS (Building Use Studies Occupant Survey) (Dykes and Baird, 2013, Leaman and Bordass, 2001)
- AMA WorkWare (Alexi Marmot Associates) ((AMA), 2004)
- DQI (Design Quality Indicator)(Prasad, 2004)

The above surveys were developed based on a five or seven-point scale for responses. They have been used widely for different types of buildings across the globe for different types of climate regions (Dykes and Baird, 2013, Oseland, 2004, Bluyssen et al., 2011). These instruments and literature review were analysed to develop a unique survey instrument for this research study (Appendix – 1).

The survey was designed to collect occupant response on the five-point Likert scale, which is widely used for feedback surveys to analyse and develop results (Allen and Seaman, 2007). This research study uses this tool for occupant responses to the questioned indoor environment quality factor. It ranges from 0 to 5:

a) 0 – Very Negative
b) 1 – Negative
c) 2 – Neutral
d) 3 – Positive
e) 4 – Very Positive

This research study aims to outline the effect of the indoor environmental quality factor on occupant's productivity.

3.5.8.1.1 Thermal Comfort

The literature review on thermal comfort identified various physical parameters that influence occupant comfort. These were ambient temperature, relative humidity, air temperature, air velocity, clothing insulation and activity level (Fanger, 1970, Fanger, 1984, Lin and Deng, 2008). This research study focuses on temperature and relative humidity. Occupant survey responses on physical parameters have been collected. The question aims to collect occupants' responses to thermal comfort using a five-point scale (Table 3.1).

3.5.8.1.2 Indoor Air Quality

It was identified from the literature review on indoor air quality that the level of Carbon Dioxide and Volatile Organic Compounds (VOC) influence the quality of indoor air (Jones, 1999, Panagiotaras et al., 2013, Langer et al., 2016). This research study focuses on measuring these parameters. The question aims to collect occupant responses to natural ventilation and mechanical ventilation, along with their response from the occupant survey on a five-point scale. It will help to map the acceptable range of carbon dioxide and VOC (Table 3.1).

3.5.8.2 Lighting and Daylighting

The research learned about lighting and daylighting outlined the importance of illuminance levels (Lux) and daylighting for visual comfort and productivity (Boyce and Association, 2001, Li and Tsang, 2008, Mansfield, 2018). This research study looks at measuring lux levels and access to daylight, outlining the ideal lux range and impact of daylight on office occupants' comfort and their productivity (Table 3.1).

3.5.8.3 Noise and Acoustics

The literature review on noise and acoustics underlined the impact of sound levels on occupant comfort and productivity in offices (Bluyssen et al., 2011, Frontczak et al., 2012, Fuks et al., 2017). The measurement of noise levels and occupant responses will assist with finding the ideal range for occupant comfort and productivity in offices (Table 3.1).

3.5.8.4 Office Layout

The literature reviewed has also included studies on office layout and its impact on occupant comfort and productivity (Shahzad et al., Haynes, 2008b, Lee, 2010, Kim et al., 2013). Analysing the layout of the occupant against their response towards the comfort levels of the layout will help to highlight and contribute to finding out more about the impact of office layout on occupant productivity (Table 3.1).

Question - How have these factors affected your productivity?

	Indoor environment factor	Very Negatively	Negatively	Neutral	Positively	Very Positively
A	Thermal comfort					
B	Natural ventilation					
C	Mechanical ventilation					
D	Low-emitting materials					
E	Illumination levels					
F	Daylight					
G	Indoor chemical & pollutant source control					
H	Acoustic quality					
I	Office layout					

Table 3.1- IEQ Factors - Survey

The researcher also aimed to develop occupant profile through the following aspects:

1 Age: Literature has indicated that the age of the occupant influences their comfort and productivity. Elderly occupants feel colder than younger occupants (Indraganti and Rao, 2010, Indraganti et al., 2015, Collins et al., 1981).

3 Gender: Literature also highlights the difference in thermal comfort and perception of comfort between the genders. Females tend to feel colder than males (Wang et al., 2018, Del Ferraro et al., 2015, Kim et al., 2013)

4 Job Profile and number of hours at the desk: The nature of the task also influences an occupant's comfort and productivity. Different tasks require varying types of body movement that lead to a rise in body temperature. Sedentary occupants tend to feel colder than lightly active occupants (de Dear et al., 1997, Brager and de Dear, 1998, De Dear and Brager, 2002, De Dear et al., 2013, Wang et al., 2018).

5 Ethnicity, the terrain of the childhood place: Ethnicity and the terrain of childhood have an impact on an occupant's thermal and air comfort (Wong and Khoo, 2003, Arens et al., 1997, Lipczynska et al., 2018).

The above questions can help to create a detailed occupant profile to perform detailed analysis and comparison amongst participant performance if needed in the future.

3.5.8.5 Physical Parameters Measurement

The research experiment consists of measuring the physical parameters using sensors. The equipment used to collect physical parameter data has improved a lot in the past decades. Earlier, big equipment was used to measure different types of parameters like temperature, humidity, carbon dioxide and light. However, sensors' data collection capacity and connectivity have improved a lot over time, with building management systems extensively using various sensors to manage the indoor environment and energy usage of the building (Jin et al., 2018). This study is going to focus on following indoor environment quality factors and parameter (Figure 3.2):

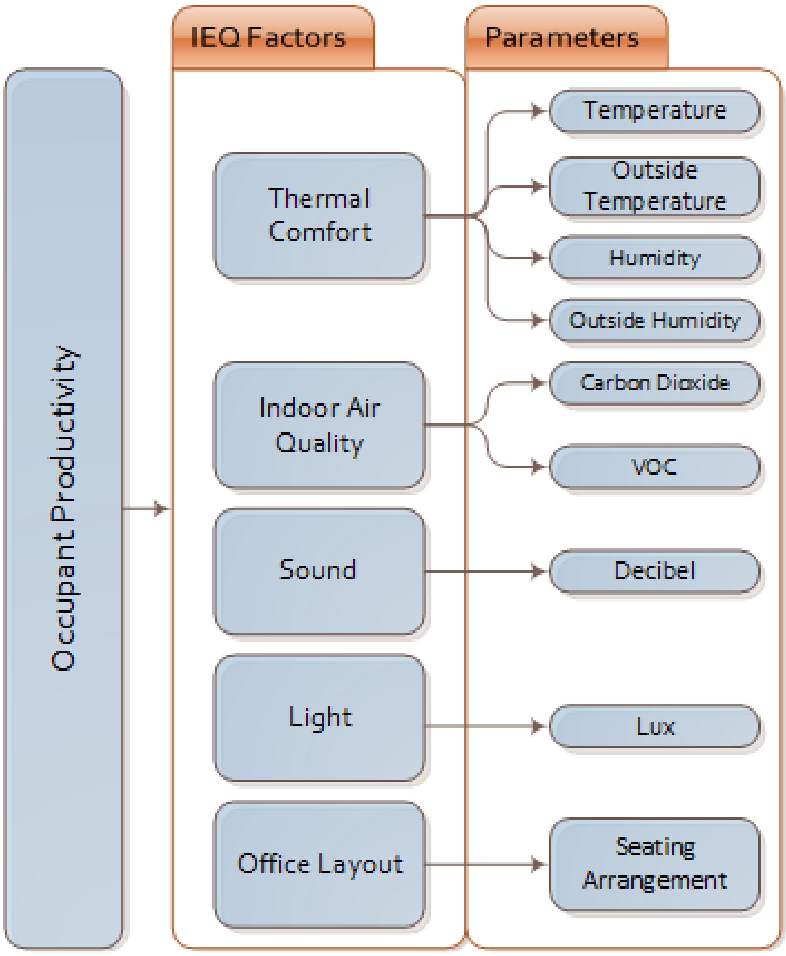


Figure 3.2 - Occupant Productivity - IEQ Factors and Parameters

This research study focuses on outlining the impact of the above mentioned indoor environmental factors and parameters on occupant productivity. It will outline the statistical relationship using equations. The research study would also present a range of practical recommendations in the form of design guidelines for the practices in the middle east.

3.6 Time Horizon

The research study aims to collect data for nine-twelve months in an office building in Doha, Qatar. This time length would help to gather detailed data on the occupant response and behaviour. It can be stated that this research would adopt a longitudinal time horizon (Appendix – 2 - PhD schedule).

3.7 Techniques and Procedures

The research study uses a literature review method to establish the state of the art of knowledge on the topic of indoor environment quality (Table 3.2). The data collection will be done using a post-occupancy evaluation method (survey, physical data collection). The sensors selected will be programmed to send measurements to an online database and will use response surface methodology to identify the relationship between indoor environmental factors and occupant productivity.

Stage	Technique
Data collection	Survey, Sensors
Data analysis	Response Surface Methodology (Mini Tab)

Table 3.2 - Data Collection and Analysis

3.8 Research Phases

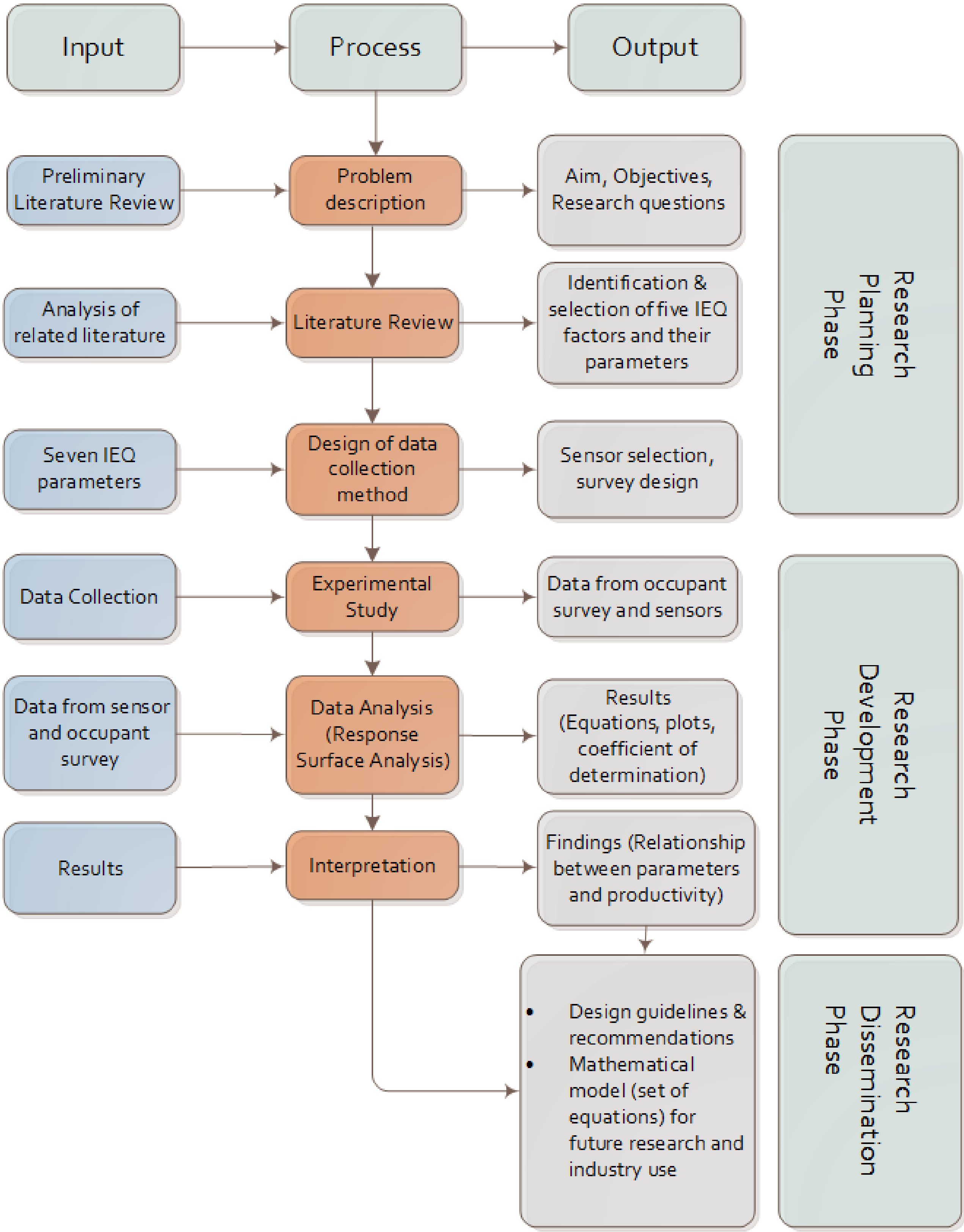


Figure 3.3 - Research Phase Diagram

3.8.1 Research Planning Phase

The research planning phase starts with problem identification. In the process of the problem description, a preliminary literature review helps to highlight the aim, objectives and research questions (Figure 3.3).

3.8.1.1 Literature Review Method

The literature review is conducted to develop the base of this research study. It collates the literature from a wide range of sources such as books, conference proceedings and journal articles. It is conducted in three steps (Figure 3.4):

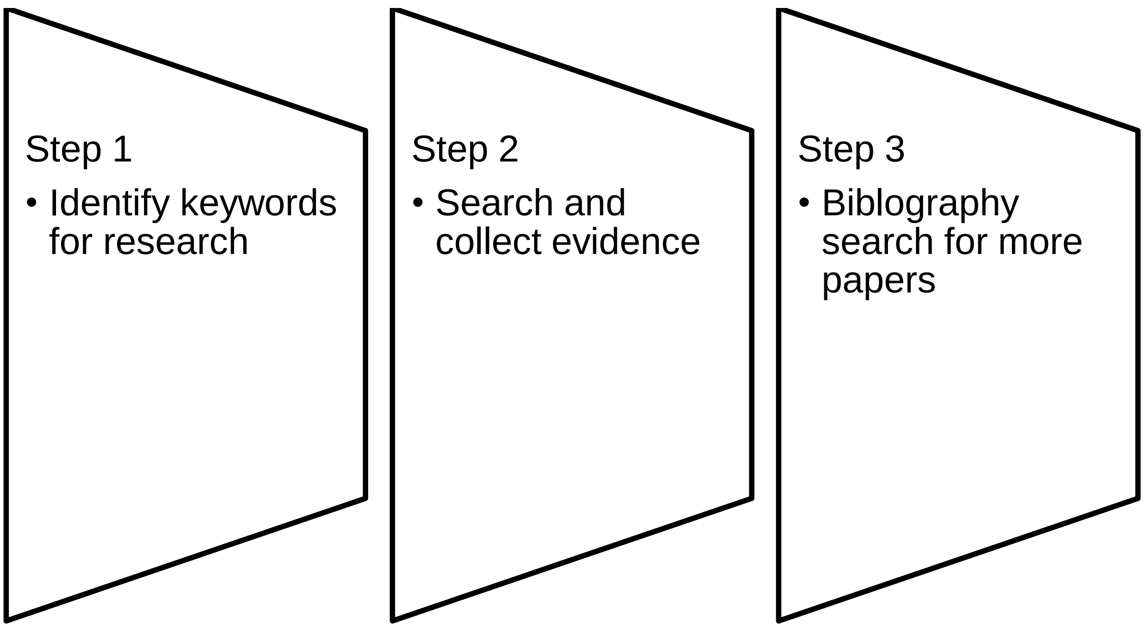


Figure 3.4 - Literature Review Method

1. The first step was to identify the keywords related to this research study. This research focuses on identifying the effect of indoor environment quality on occupant productivity in a workplace environment in the middle-eastern region. It led to the identification of occupant comfort,

occupant productivity, indoor environment quality, thermal comfort, indoor air comfort, visual comfort, acoustic comfort, and office layout and occupant satisfaction.

2. The researcher used the University of Wolverhampton's library online search engine and Google Scholar for the literature research and review.
3. The literature search and collection was followed by exploring the bibliographies and finding more relevant literature for the review.

It led to the identification of five indoor environment quality factor and seven parameters that have a significant impact on occupant productivity in a workplace environment. A literature review was also conducted to identify relevant research design (data collection and analysis) for this research study.

3.8.2 <u>Research Development Phase</u>

The research development activities include an experimental study to establish the IEQ factors and occupant productivity relationship model. The experimental study was conducted using Post Occupant Evaluation (POE) method in Doha, Qatar, and is quantitative. The experimental study aimed to measure seven indoor environment quality parameters under five indoor environmental factors and collect occupant responses towards those parameters. The research development phase also includes data analysis. It uses the design of experiments discipline to design the data analysis methodology.

3.8.2.1 Design of Experiment

The design of the experiment is a methodology for systematically applying statistics to experimentation. It is used to identify the relationship between input variables and the response variable or output variables (Hockman and Berengut, 1995, Jiju, 2003) (Figure 3.5). The design of experiment was invented in by R.A. Fisher in the 1920s and has been applied to the automobile industry, defence industry, agriculture and petrochemical industries to develop or improve a product/process or service(Telford, 2007). The design of the experiment is highly useful in conducting experiments where some of the input factors are uncontrollable. This study aims to identify the relationship between indoor environmental quality and occupant productivity in an office environment. The results are aimed to be applied for a practical purpose (design recommendations). Hence, it is necessary to experiment with minimum intervention to yield the most practical and uninfluenced measurements in an office environment in the Middle East (Qatar). Thus, the design of the experiment is highly appropriate discipline to design this study's research methodology.

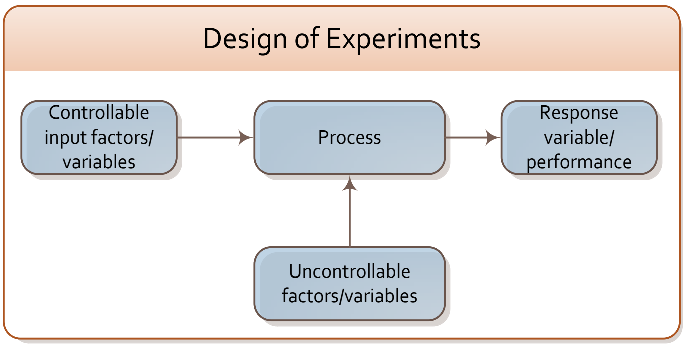


Figure 3.5 - Design of Experiment

3.8.2.1.1 Response Surface Methodology

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques used to develop and interpret polynomial equations (Box and Draper, 1987, Montgomery and Myers, 1995). It was initially developed and adopted by the engineering and industrial world. However, it is becoming increasingly popular in other scientific fields such as social science research (Meyer, 1963, Ximénez and San Martín, 2000). It is highly useful in situations where there are several unknown input variables (x_1, x_2, x_k) that have a potential influence on a performance measure, called the response (y). The main aim of the RSM model is to investigate independent variables, test empirical models for developing an appropriate relationship between the response and the input variables and to optimise methods for estimating values of x_1, x_2,….,x_k that produce the most desirable value of y(Ximénez and San Martín, 2000, Box and Draper, 1987, Hill and Hunter, 1966).

$f = y = f(x_1, x_2, \ldots\ldots, x_k) + \varepsilon$

y = response/ performance variable

x = input variables

ε = noise or error observed in the response y

The surface represented by $f(x_2, \ldots\ldots, x_k)$ is called the response surface. It can be represented graphically (three-dimensional space or as contour plots) that helps to understand the shape of the response surface (Figure 3.6).

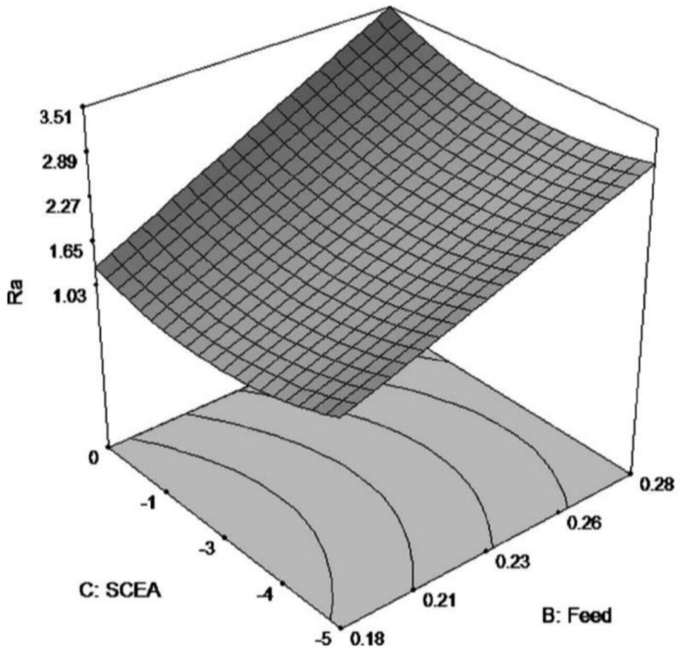


Figure 3.6 - Response surface graph (example) (Noordin et al., 2004)

The research study uses response surface methodology to generate the relationship between seven parameters (under five indoor environmental factors) and occupant response (survey response) (Table 3.3).

IEQ factor	Parameter	Measured by	Input Variable	Response/ performance variable
Thermal comfort	Temperature	Sensor	x_1	y (calculated from the company's HR system & survey responses)
	Relative humidity	Sensor	x_2	
Indoor Air Quality	Carbon dioxide	Sensor	x_3	
	Volatile Organic Compound	Sensor	x_4	
Lighting	Lux level	Sensor	x_5	
Noise	Sound level	Sensor	x_6	
Office Layout	Seating Arrangement	Researcher (Office plan)	x_7	

Table 3.3 - RSM variable table

The participating organisation has two offices in Qatar Science and Technology Park (QSTP). Around 40 employees are employed by the organisation and participated for around one year (Two surveys a month).

$$A \times B \times C = 40 \times 12 \times 2 = 960$$

A = Number of employees

B = Number of months

C = Survey/month

In an initial calculation, the experiment indicated to have a maximum of 960 data points. By considering data loss of 25% due to employee holidays, data cleaning, then experiment provides 500-600 data points. The survey response would be time stamped. Hence, they can be correlated with the sensor data for each data point. In the response surface methodology term, these data points can also be termed as *runs*. The runs would enable us to calculate and generate several relationship equations between seven input variables and the performance variable(y).

The response surface analysis will produce a model consisting of a set of equations for each variable. Figure 3.7 shows an example of how response surface equations look in a 3D graph.

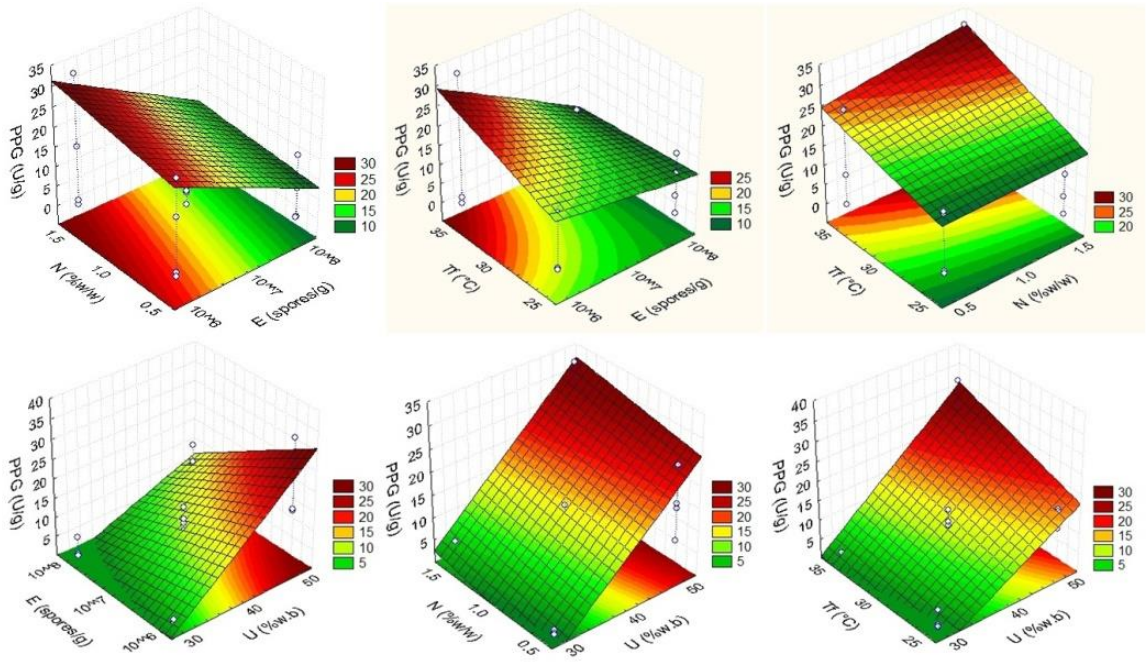


Figure 3.7 - Set of response surface equations' graph (example))(Alcântara et al., 2013)

The response surface analysis was conducted using Minitab software. The researcher used a backward elimination procedure to conduct response surface analysis (Figure 3.8). This process is highly useful to eliminate any input variable with low effect on output variable in any multiple regression analysis. Backward elimination starts with all the input variables in the model and eliminates one input variables in each run with the least effect on the model. This stepwise procedure continues until the no input variables in the model have a p-value greater than the value specified (alpha to remove) (Figure 3.9). The researcher used 0.1 as alpha to remove the value in this experiment. It produces 90% confidence results.

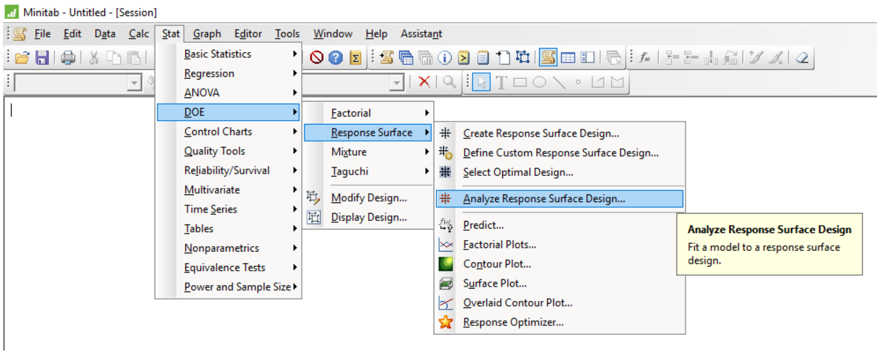


Figure 3.8 - Response Surface Methodology – Minitab – Step 1

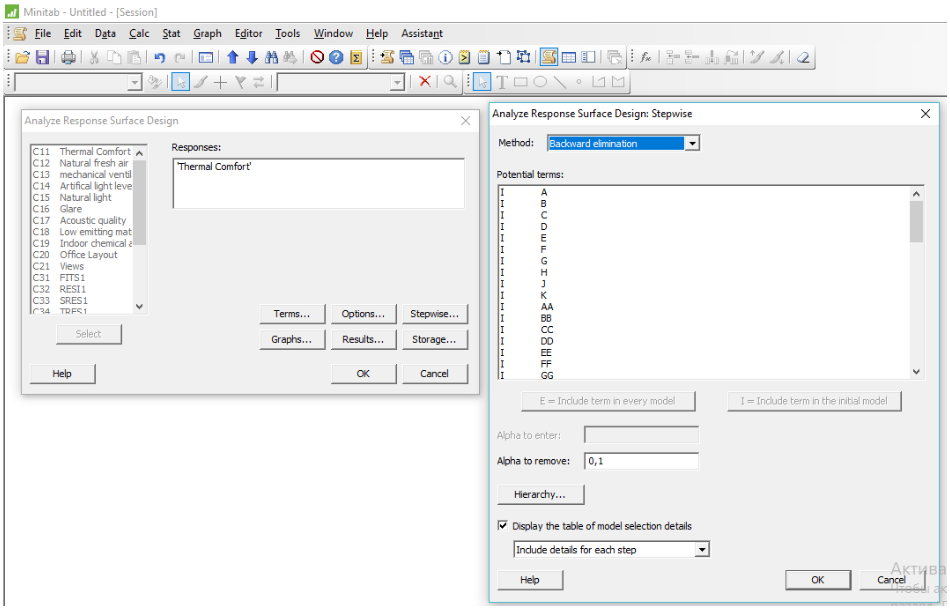


Figure 3.9 - Response Surface Methodology - Minitab - Step 2

3.8.3 Research Dissemination Phase

The research dissemination phase involves the development of design guidelines and recommendations for office design in Qatar and middle-east. These recommendations can help architects, building managers and other built environment professionals to design sustainable and conducive buildings that would help to improve occupant productivity. The research also produced the set of equations (mathematical model). These mathematical models can be used by future research and industry use, with this model being used as an example to investigate the impact of indoor environmental quality on occupant productivity in educational buildings. This model can be used to further investigate the inter-relationship between various indoor environmental factors, with the study being used as an example to other, similar studies to be conducted in different climatic regions.

3.9 Data Collection and Analysis

This section presents vital aspects of data collection and analysis of the research study (Figure 3.10). The research study methodology proposed to measure the physical parameters of indoor environment quality while simultaneously collecting the occupant response. As mentioned in the previous section, data collection and analysis was done by the adopted research design.

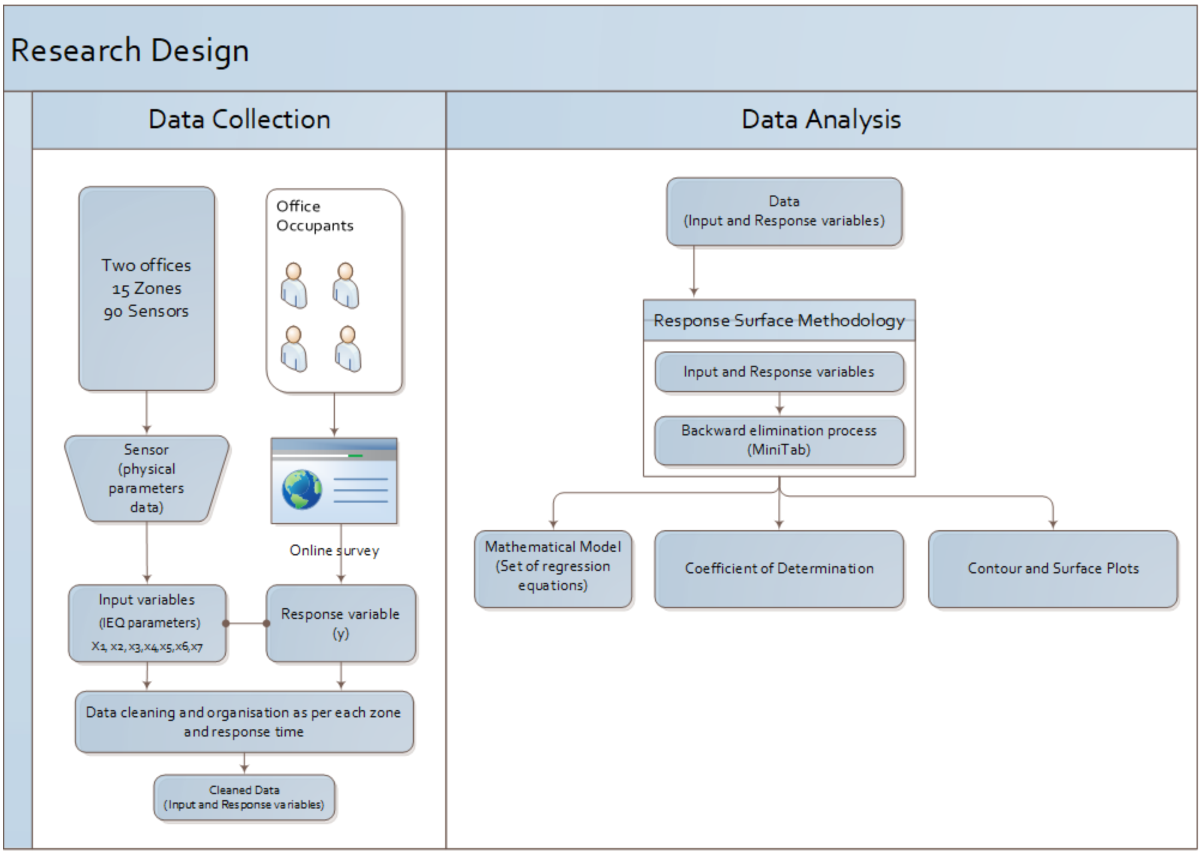


Figure 3.10 - Research Design - Data Collection and Analysis

3.9.1 Data Collection

The literature review led to the selection of using Post Occupancy Evaluation (POE) for data collection. Researchers obtained the ethical approval for data collection (Appendix – 3). Data collection in this research project involved two types of data; physical data and survey data.

3.9.1.1 Indoor Environment Quality factors (Physical Parameters)

The researcher used a range of sensors connected with a base data monitoring unit and a cloud-based system to store the collected data.

Figure 3.11 - BRE Base unit

Sensors send the measurement data to the base unit (Figure 3.11) that uploads the data to the online database. This then stores the collected data as per the data and their assigned code. The data can be sorted, managed and downloaded from the online dashboard on the data management vendor's website (Figure 3.12).

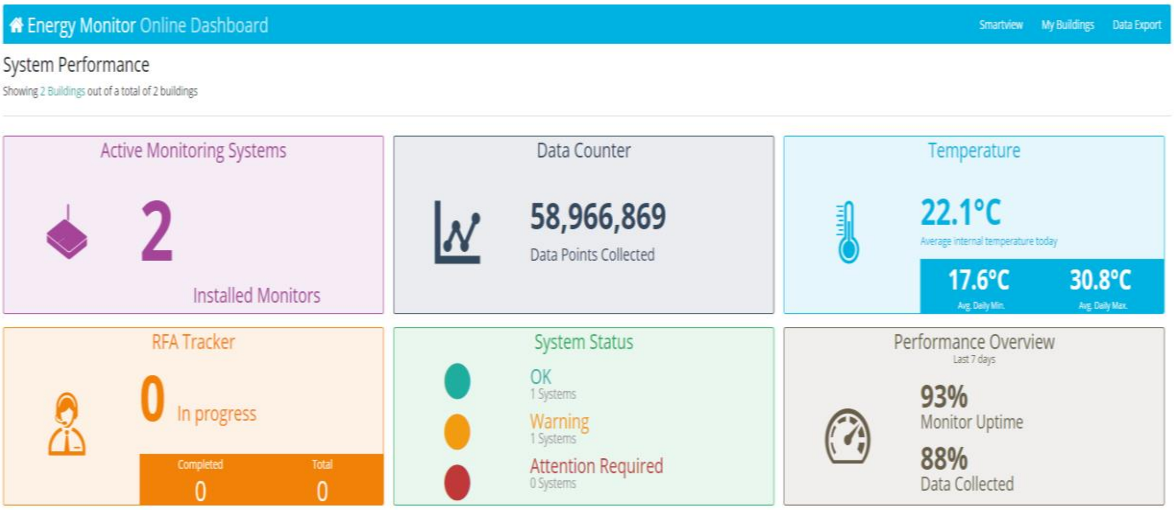


Figure 3.12- Data Collection - Online Data Management Dashboard

The organisation provided access to two offices located in Qatar Science and Technology Park, Doha, Qatar. There were numerous rooms in these offices. The researcher created 15 zones to collect streamlined data (Table 3.4). Each room was assigned as a zone, and each zone had sensors collecting data on temperature, humidity, carbon dioxide, VOC, light levels (Lux) and sound (Decibels). The organisation has one main office, and a smaller office called a Techno Hub. The main office has 12 zones, and the Techno Hub has three zones (Figure - 3.13).

Offices	Data Collection Zone
Main Office	1,2,3,4,5,6,7,8,9,10,11,12
Techno Hub	13,14,15

Table 3.4 - Data Collection - Offices and Zones

During the data collection time, 58.9 million data points were collected by 90 sensors placed in 15 zones. Two monitoring devices connected them (Figure - 3.14).

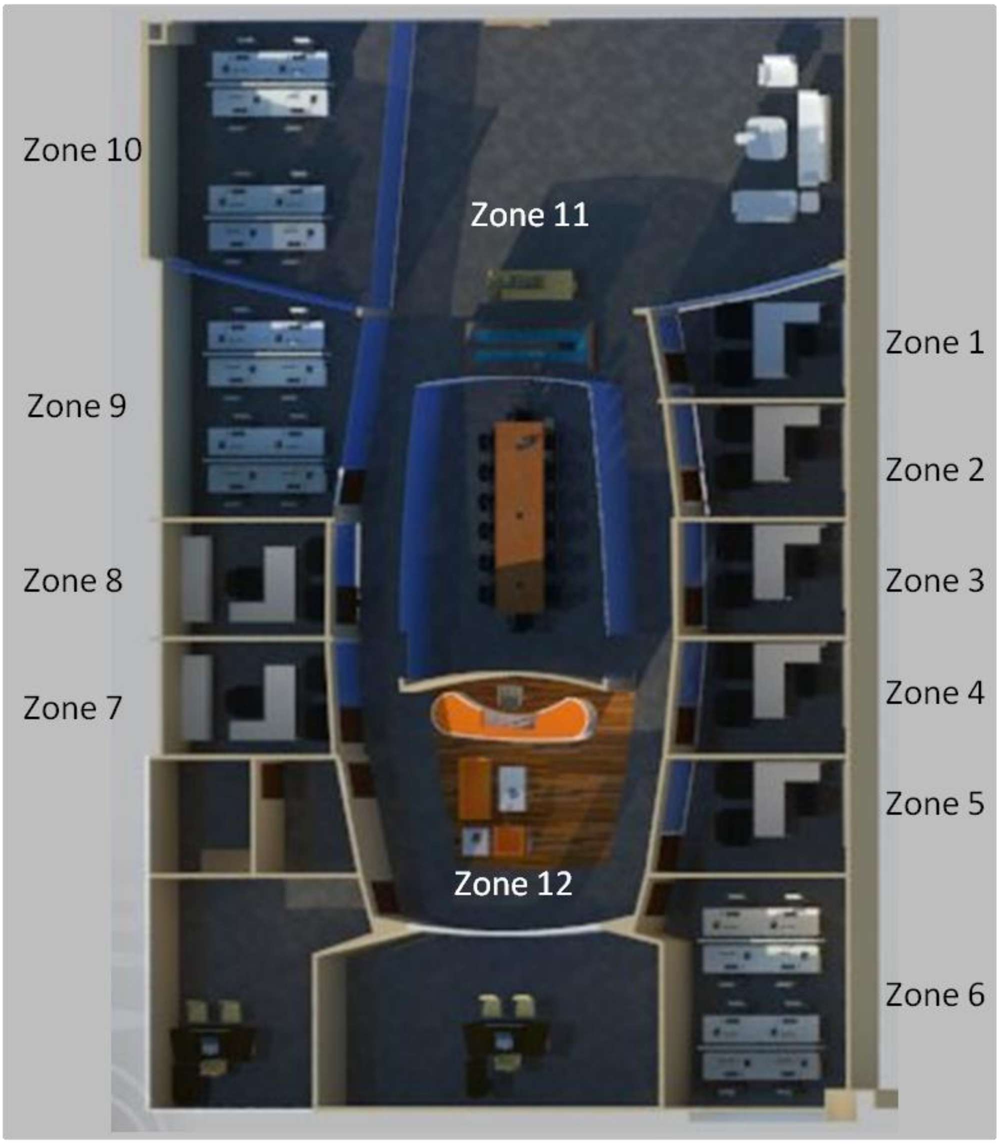


Figure - 3.13 - Office plan with Zones

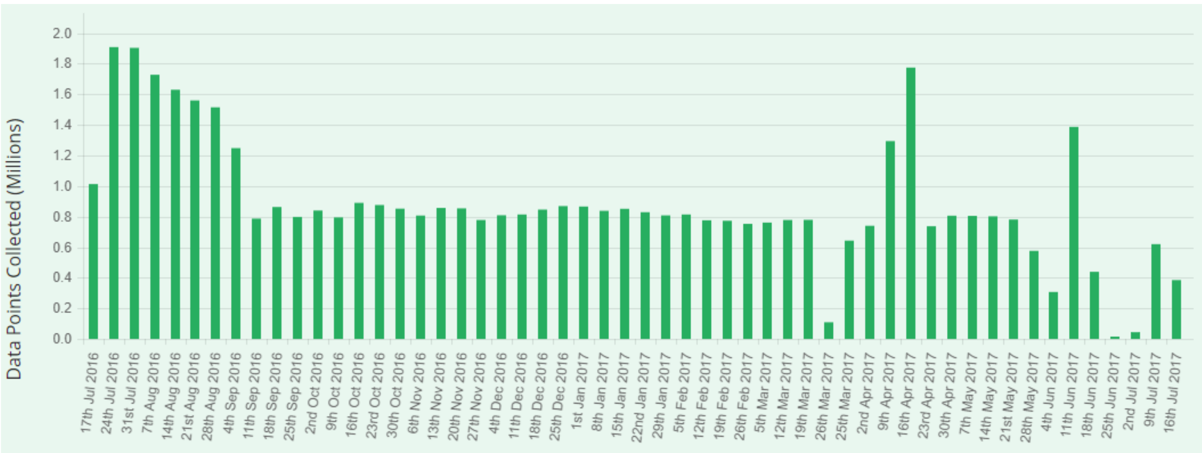


Figure - 3.14 - Data points Collection Graph

3.9.1.1.1 Thermal comfort

Thermal comfort is one of the physical parameters set to be measured in this experiment. The researcher used the T-3524C sensor (Figure - 3.15) to measure indoor ambient temperature and relative humidity.

Figure - 3.15 - T-3524C sensor

This research study also used the Vantage Pro2 sensor (Figure 3.16) to measure outside temperature and relative humidity.

Figure 3.16 - Vantage Pro2 Sensor

3.9.1.1.2 <u>Indoor Air Quality</u>

The literature review identified carbon dioxide and VOC as physical parameters to be measured in indoor air quality. The researcher also used a T3571 sensor (Figure 3.17) to measure carbon dioxide and a T3576 sensor (Figure 3.18) to measure VOC. The T3571 presents carbon dioxide data in PPM (Particles Per Million), while the T3576 presents VOC data in percentage VOC free air (by volume).

Figure 3.17 - T3571 sensor

Figure 3.18 - T3576 sensor

3.9.1.1.3 Lighting and Daylighting

The literature review outlined lighting and daylighting as one of the factors that influence occupant productivity, using T3551 (Figure 3.19) to measure lux levels in the office.

Figure 3.19 - T3551 sensor

3.9.1.1.4 Noise and Acoustics

As the sound level also has an impact on occupant comfort and productivity, the researcher has used T-3576 (Figure 3.18) to measure the sound level in the office.

3.9.1.1.5 Office Layout

Office layout also influences occupant comfort and productivity. The researcher has surveyed the office and created zones and listed the occupants in each zone. The survey reply was compared with the seating arrangement of the zone (Figure - 3.13). The researcher collated the seating arrangement of the occupants from the Human Resource department. The rooms were divided into different zones and occupants were put into the allocated zones. Results were created based on this analysis to outline the impact of seating arrangement (office layout) on occupant comfort and productivity.

3.9.1.2 Survey Data (Occupant Response)

Online survey data were collected using the company's Human Resource management system. The HR manager sent emails fortnightly to employees to submit their responses.

1	02/05/2016						01/08/2016							22/11/2016
2	15/05/2016						02/08/2016						02/11/2016	
3		15/05/2016		15/06/2016			02/08/2016	15/08/2016			03/10/2016	18/10/2016	01/11/2016	
4													01/11/2016	
4	03/05/2016										04/10/2016			23/11/2016
5	01/05/2016	16/05/2016		16/06/2016			02/08/2016				04/10/2016	19/10/2016		
6		15/05/2016	01/06/2016	15/06/2016				15/08/2016			04/10/2016	19/10/2016		
7	02/05/2016						02/08/2016							22/11/2016
8	01/05/2016	15/05/2016	01/06/2016				01/08/2016	15/08/2016			04/10/2016	17/10/2016	01/11/2016	
9	01/05/2016	15/05/2016	01/06/2016	15/06/2016			01/08/2016	15/08/2016			03/10/2016	18/10/2016		22/11/2016
10	16/05/2016	01/06/2016		15/06/2016			01/08/2016	15/08/2016			03/10/2016	19/10/2016	01/11/2016	22/11/2016
11	02/05/2016													
12	01/05/2016	15/05/2016						15/08/2016					03/11/2016	22/11/2016
13	01/05/2016			16/06/2016				16/08/2016			03/10/2016	17/10/2016	01/11/2016	22/11/2016
14	01/05/2016			16/06/2016			01/08/2016	15/08/2016				17/10/2016	02/11/2016	
15	05/05/2016	16/05/2016									03/10/2016			22/11/2016
16	01/05/2016	16/05/2016	02/06/2016	16/06/2016			02/08/2016	17/08/2016			06/10/2016	17/10/2016	03/11/2016	22/11/2016
17	01/05/2016	15/05/2016		15/06/2016			01/08/2016					17/10/2016	01/11/2016	
18	03/05/2016	15/05/2016												
19		15/05/2016	01/06/2016	15/06/2016			01/08/2016	15/08/2016			03/10/2016	17/10/2016	01/11/2016	22/11/2016
20	01/05/2016			15/06/2016										
21	03/05/2016			16/06/2016				17/08/2016				17/10/2016		
22		15/05/2016	02/06/2016											
23	01/05/2016	17/05/2016	02/06/2016	16/06/2016			02/08/2016	15/08/2016			03/10/2016	17/10/2016		
24		15/05/2016	01/06/2016	15/06/2016			01/08/2016				03/10/2016	17/10/2016	01/11/2016	
25	01/05/2016	15/05/2016		16/06/2016										
26	02/05/2016	15/05/2016		16/06/2016							05/10/2016	18/10/2016	02/11/2016	22/11/2016
27	01/05/2016		01/06/2016	16/06/2016			01/08/2016	17/08/2016			03/10/2016	17/10/2016	03/11/2016	22/11/2016
28		15/05/2016	02/06/2016											
29	01/05/2016	15/05/2016												
30	03/05/2016	15/05/2016		16/06/2016			02/08/2016	17/08/2016			03/10/2016		03/11/2016	
31	03/05/2016													
32			02/06/2016				01/08/2016				04/10/2016			22/11/2016
33							01/08/2016					17/10/2016		
34							01/08/2016	15/08/2016			03/10/2016	17/10/2016		22/11/2016
35							01/08/2016	15/08/2016			03/10/2016	17/10/2016	01/11/2016	22/11/2016
36								15/08/2016			04/10/2016			
37												17/10/2016		
38												17/10/2016		
	25	20	11	18			20	17	0	0	20	21	16	15

Table 3.5 - Survey Data Collection Snapshot

A total of 650 survey data points were collected from July 2016 to July 2017 (Table 3.5). Both survey and sensor data was stored on a local hard disk stored in a secure locker.

3.9.2 Data Organisation and Cleaning

The data collection started in May 2016. The data from the sensor and survey has been stored online and on a local hard disk. Data organisation and cleaning was done by the researcher (Figure 3.20). The sensor data was organised as per each zone. First, the reading of all the sensors was averaged to 15 minutes to ensure that each sensor readings have been average at the same time interval. The survey data was organised as per each zone. The dates of response were used to clean the sensor data. The researcher used the sensor data from the day before and the date of response for analysis. Later, the sensor data and survey data were collated in the excel file as per each zone and response date.

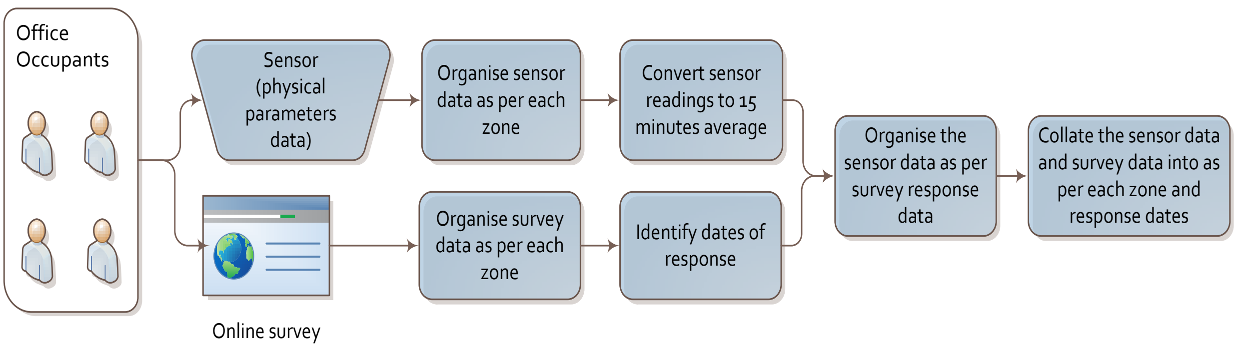


Figure 3.20 - Data Organisation and Cleaning Process

The data has been organised as per each zone. The responses of an occupant in a zone are organised as per each sensor reading (Table 3.6).

Zone *x*	Date *a*	Sensor 1	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 2	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 3	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 4	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 5	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 6	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 7	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
	Date *b*	Sensor 1	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 2	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 3	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 4	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 5	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 6	Response 1	Response 2	Response 3	Response 4	Response 5	Response n
		Sensor 7	Response 1	Response 2	Response 3	Response 4	Response 5	Response n

Table 3.6 - Sensor Data Organisation Table

3.9.3 Data Analysis

This section outlines the data analysis strategy of the research experiment. The experiment follows a Response Surface Analysis methodology for data analysis. It provides a framework for analysing the IEQ parameter data and occupant survey data to develop various statistical relationship models that outline the degree of influence of each IEQ factor on occupant productivity.

3.9.3.1 Occupant Profile

Survey responses have been analysed to generate participants' profile. There are eight profile questions in the survey.

Q1. How many years have you worked in this workplace?

a) Less than one year
b) 1 -2 years
c) 3 -5 years
d) More than five years

The first profile question collates data on employees' time at the workplace (Figure 3.21). The data indicates that half of the participants have only spent less than one year at the workplace. About one-fourth of the participants have been working for one to two years, and one-fifth have associated with the workplace for between three to five years. Only five per cent of the workforce has spent more than five years at this workplace.

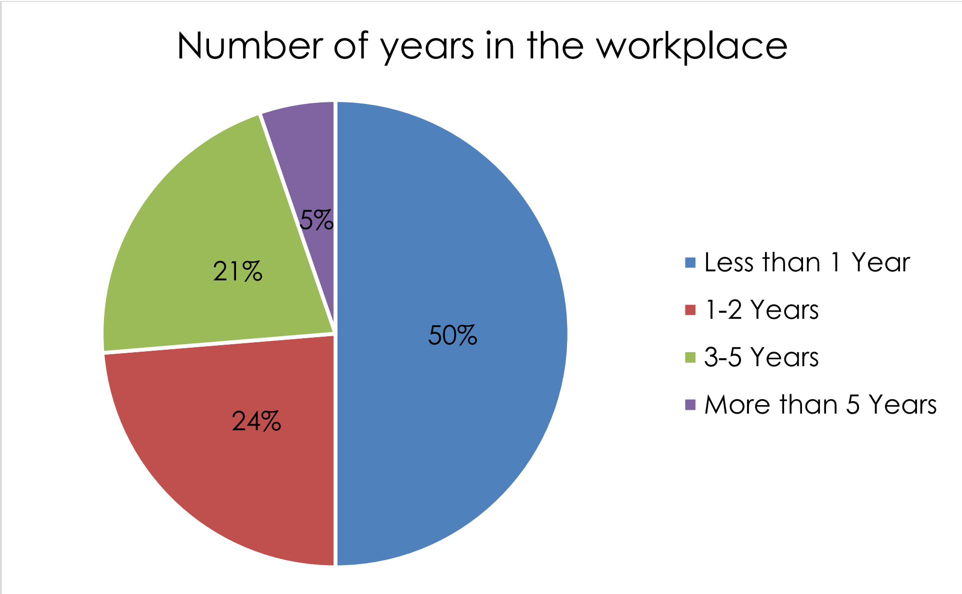


Figure 3.21 - Survey Response - Number of years in the workplace

Q2. In a week, how many hours do you spend at your desk in the office (do not include field work)?

a) Less than 30
b) Between 30 – 40
c) More than 40

The second question outlines the number of hours spent at the workplace (Figure 3.22). This data can help highlight any correlation between occupant response and a number of hours worked in the office. The data suggests that half of the workforce spends more than 40 hours in the office per week. About 34% of participants spend between 30 to 40 hours per week in the workplace. Only 16% of participants worked less than 30 hours per week.

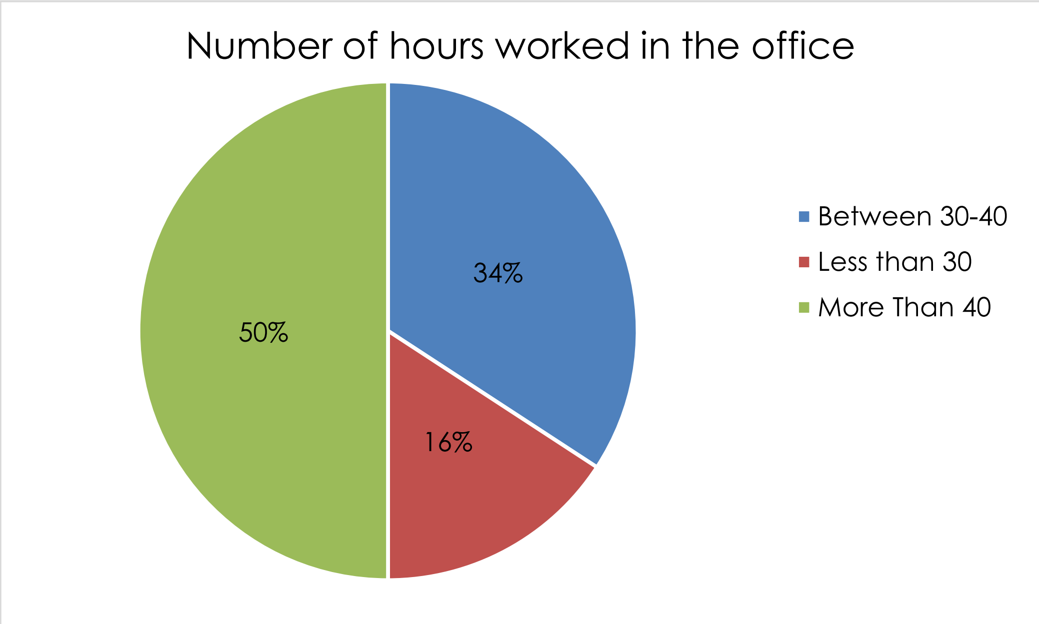


Figure 3.22 - Survey Response - Number of hours work in the office

Q3. How would you describe your job profile?

a) Administrative support

b) Technical

c) Professional (GSAS/ Research)

d) Managerial/supervisory

e) Other

The third question collates data on the job profile of the survey participants (Figure 3.23). There are 52% GSAS and research professionals participating in the survey. About one-fourth of the participants is support staff working in the administration. There are 5% of participants in a managerial/ supervisory position, 3% in technical and 16% participants in another position. This data will be analysed with occupant response to identifying any patterns of response based on the profiles of the participants.

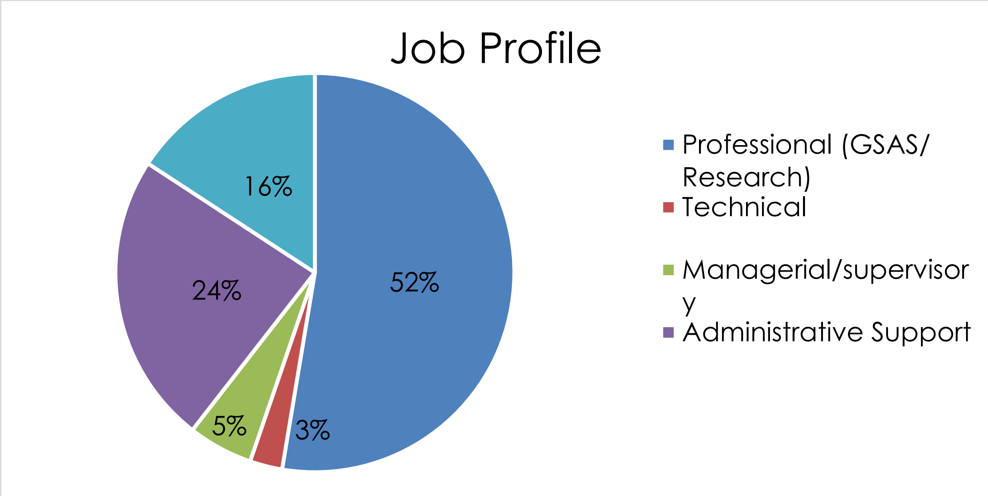


Figure 3.23 - Survey Response - Job Profile

Q4. What is your age?

a) Below 30

b) 31 – 50

c) Over 50

This question outlines the age profile of the survey participants (Figure 3.24). The majority (61%) of the participants belong to the 31-50 age group, 34% of participants are aged below 30, and 5% are above 50. The literature has indicated that age significantly influences occupant physical comfort. The participant's age data would help to analyse any difference in response based on the participant's age.

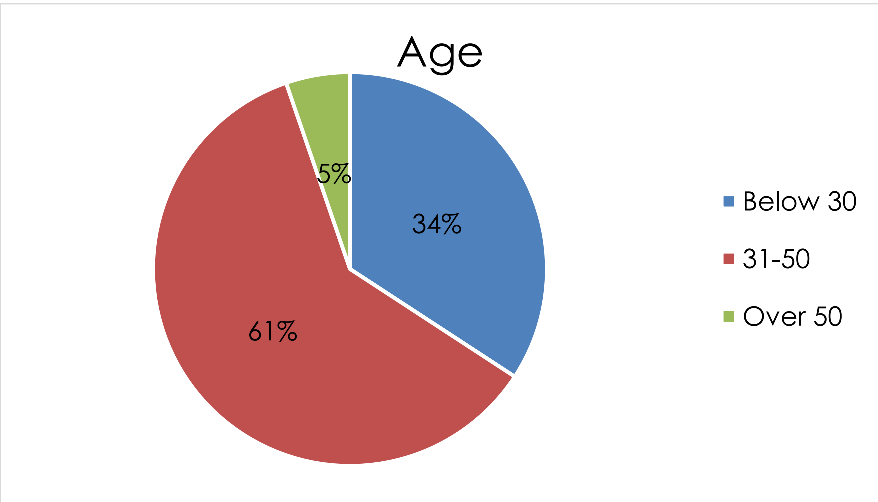


Figure 3.24 - Survey Response - Age Profile

Q5. What is your gender?

a) Female

b) Male

Question five collates the data on the gender ratio of the participants (Figure 3.25). The literature review highlighted that male and female have different physical comfort preferences. The data shows that 71% are male and 29% are female. This data would help to identify any correlation between gender and responses of the participants.

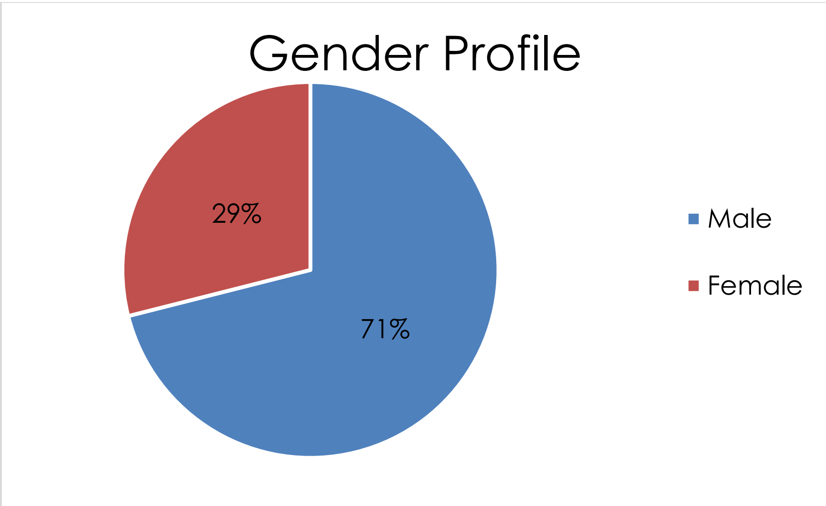


Figure 3.25 - Survey Response - Gender Profile

Q6. What is your ethnicity?

a) Caucasian
b) South Asian
c) Far East Asian
d) Middle Eastern
e) African
f) Others

Question six collates data on participants' ethnicity (Figure 3.26). The existing studies highlight that humans with different ethnicity background have different comfort preferences. The local geographic conditions influence the environmental preference of the residents. The data indicates that the participant profile is highly diverse. There are 39% of participants with Middle Eastern ethnicity, 32% South Asian, 13% African and 10% Caucasian, and 3% Far East Asian and 3% others. A comparative analysis of participants' response and ethnicity would highlight any correlation between the two aspects.

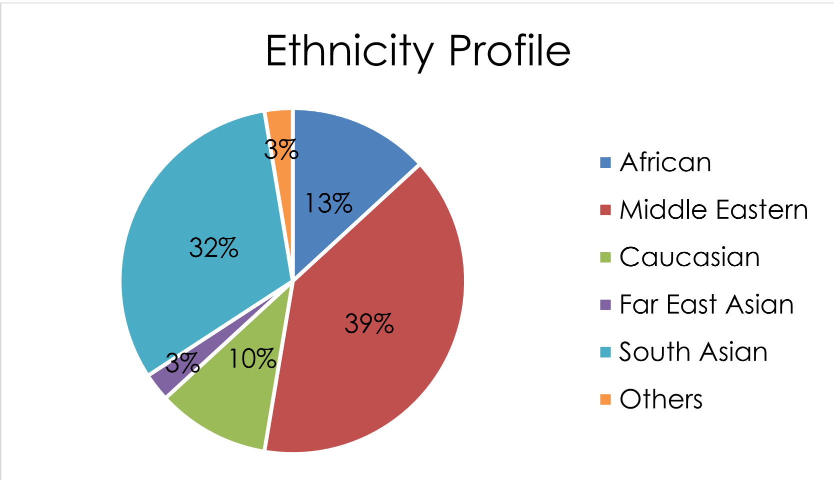


Figure 3.26 - Survey Response - Ethnicity Profile

Q7. What is your highest level of education?

a) High school
b) Bachelor degree
c) Master degree
d) Doctorate
e) Others

Question seven outlines the educational qualification of the participants (Figure 3.27). The data highlights that the majority (53%) of the participants hold a bachelor's degree. 39% of participants hold a master's degree, 5% are high school educated, and 3% hold a doctorate.

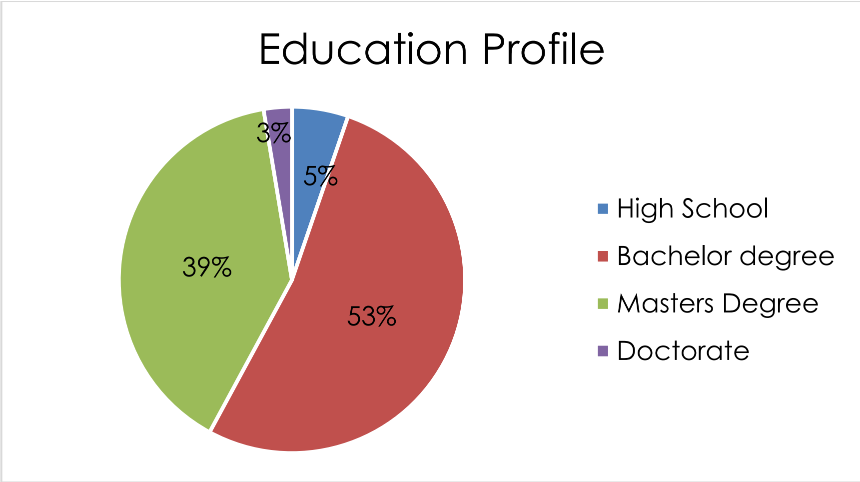


Figure 3.27 - Survey Response - Education Profile

The analysis from the above questions would help to develop employee profiles. These profiles would be used to generate an individual's productivity pattern and their response to various indoor environment quality factors. These analyses can provide unique relationships between occupant productivity and indoor environmental quality in offices. These occupant profiles also state that participating occupants were from a diverse background, both genders, diverse age group, assigned to perform different tasks. It highlights that results are not based on a single category or type of occupants.

4 Results and Findings

This chapter presents the results and findings of the response surface analysis conducted on the data collection. It outlines the effect of various indoor environmental quality factors on occupant comfort and productivity. The chapter is divided into nine parts. The first section introduces the data analysis chapter and outlines the factors covered in the analysis of each of the indoor environmental factors and their impact on occupant productivity. Section two describes the results of thermal comfort, followed by an outline of the results on the effect of indoor air quality (natural air) on occupant comfort and productivity. Section four introduces the results on the effect of indoor air comfort (mechanical ventilation) on occupant comfort and productivity. Section five presents the results on the effect of indoor air comfort (VOC) on occupant comfort and productivity; then section six refers to the results on the effect of noise on occupant comfort and productivity. Section seven presents the result on the effect of illumination levels on occupant comfort and productivity which is then followed by explanations of the effect of natural light on occupant comfort and productivity and office layout on occupant comfort and productivity. To finalise, there is a summary of the main results and findings.

4.1 Introduction

The research study focused on five indoor environmental quality factors and eight response surface analyses, which were conducted to outline eight relationship models. These are:

1. Thermal comfort
2. Indoor Air comfort
    a. Carbon Dioxide - Natural Air
    b. Carbon Dioxide – Mechanical Ventilation
    c. Volatile Organic Compound
3. Acoustic comfort
    a. Sound level
4. Visual Comfort
    a. Illumination (Lux) level – Artificial light
    b. Natural light
5. Office layout

Response surface analysis for each physical parameter produced the following analysis:

- P-values for the independent factors their square and 2-way interactions

This p-value testing is used to identify any factor that has any effect on the output variable (productivity) (Montgomery et al., 2009). The ANOVA is done using α=0.1.

If p-value ≥ 0.1, it indicates strong evidence of null hypothesis.

If p-value ≤ 0.1, it indicates strong evidence against the null hypothesis, hence rejecting the null hypothesis.

- R square (coefficient of determination)

  Coefficient of determination is used to identify the significance of the relationship between input variables and the output variable. Higher the value, higher is the impact of input on output. Values above 65% are considered relevant and reflect that input variable have a significant impact on the output variable (Nagelkerke, 1991). The R square values presented are adjusted R square value of the analysis. Adjusted r square calculates the variance of significant input variables as compared to all input variables. It shows a more accurate representation of the relationship between the input and output variable.

- Residual Plots

  Residual plots are used to determine the fit of the model. They represent the behaviour of the residuals. It is used in conjunction with the coefficient of determination, to confirm the indication of fit highlighted by the R square value.

- Regression equation

  The response surface analysis produces a regression equation. It is a mathematical representation of the relationship between input and output variables and is an equation that can be used to predict the output by filling the input variables. The researcher has a word file for all of the response surface analysis conducted for the indoor environmental quality factors. All of the backward elimination steps are included in this file. Due to the length of this file (700 pages), it will be available as a soft copy, along with data collection files (excel). For example, one backward elimination procedure has been attached in appendix – 4.

- Pareto Chart

  Pareto charts are also used to identify the effect of input variables on the output variable. It presents a reference line on a standardised effect to present the variables with high and low effect.

- Contour and surface plots

  Contour and surface plots are used to show the interaction between on output variable and two input variable. They have been used to determine peak performance range for input variables.

4.2 Thermal Comfort

This section presents the results achieved by conducting response surface analysis of thermal comfort using sensor data and occupant response. It has highlighted the following:

- P-values for the independent factors their square and 2-way interactions (Analysis of variance)
- R square (coefficient of determination)
- Residual Plots
- Regression equation
- Pareto Chart

- Contour plots
- Surface Plots
- Summary

4.2.1 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	47	357.54	7.607	18.99	0.000
Linear	15	22.688	1.513	3.78	0.000
Temperature	1	2.847	2.847	7.11	0.008
Relative Humidity	1	7.036	7.036	17.56	0.000
Outside temperature	1	6.236	6.236	15.56	0.000
Outside Relative Humidity	1	2.568	2.568	6.41	0.012
CO2	1	0.000	0.000	0.00	0.994
Sound	1	0.624	0.624	1.56	0.213
Light	1	0.010	0.010	0.03	0.873
VOC	1	1.292	1.292	3.22	0.073
Kind of Workspace	4	1.879	0.470	1.17	0.323
Do you sit near (wall type):	3	6.440	2.147	5.36	0.001
Square	4	152.94	38.237	95.44	0.000
Temperature*Temperature	1	147.55	147.55	368.29	0.000
Relative Humidity*Relative Humidity	1	1.561	1.561	3.90	0.049
Outside temperature*Outside temperature	1	5.968	5.968	14.90	0.000
Outside Relative Humidity*Outside Relative Humidity	1	2.822	2.822	7.04	0.008
2-Way Interaction	28	37.072	1.324	3.30	0.000

Temperature*CO2	1	2.403	2.403	6.00	0.015
Relative Humidity*Outside temperature	1	3.802	3.802	9.49	0.002
Relative Humidity*Do you sit near (wall type):	3	6.024	2.008	5.01	0.002
Outside temperature*Sound	1	1.345	1.345	3.36	0.068
Outside temperature*Kind of Workspace	4	4.778	1.194	2.98	0.019
Outside Relative Humidity*Sound	1	2.373	2.373	5.92	0.015
CO2*Kind of Workspace	4	8.210	2.053	5.12	0.001
Sound*VOC	1	1.511	1.511	3.77	0.053
Sound*Kind of Workspace	4	5.154	1.289	3.22	0.013
Light*VOC	1	2.731	2.731	6.82	0.009
Light*Kind of Workspace	4	5.489	1.372	3.43	0.009
VOC*Do you sit near (wall type):	3	6.551	2.184	5.45	0.001
Error	317	127.00	0.401		
Lack-of-Fit	313	126.00	0.403	1.61	0.352
Pure Error	4	1.000	0.250		
Total	364	484.54			

Table 4.1 - Analysis of Variance - Thermal Comfort

The experiment was based on the following hypothesis,

- H_0 = Variable does not affect thermal comfort
- H_{alt} = Variable affects thermal comfort

The ANOVA is done using α=0.1.

If p-value ≥ 0.1, it indicates strong evidence of null hypothesis.

If p-value ≤ 0.1, it indicates strong evidence against the null hypothesis, hence rejecting the null hypothesis.

Based on the ANOVA, the following factors affect thermal comfort and its impact on the productivity of occupants (Table 4.1):

1. Temperature
2. Relative humidity
3. Outside Temperature
4. Outside Relative Humidity
5. VOC
6. Wall type
7. Temperature* Temperature
8. Relative Humidity* Relative Humidity
9. Outside Temperature*Outside Temperature
10. Relative Humidity*Wall Type
11. Outside Temperature* Sound
12. Outside Temperature* Kind of workspace
13. Outside Relative Humidity*Sound
14. CO_2*Kind of Workspace
15. Sound*VOC
16. Sound*Kind of Workspace
17. Light*VOC
18. Light*Kind of Workspace

4.2.2 The Coefficient of Determination (Multiple Correlation Coefficient)

The coefficient of Determination or R-square defines the proportion of variance and the regression model (Nagelkerke, 1991). Regression analysis indicates the adjusted R-square (coefficient of determination) value to be 73.79%. It indicates that 74% of the data fits the regression. It highlights that there is a significant relationship between dependent and independent factors.

4.2.3 Residual Plots

Residual plots help to determine the fit of the model data (Hicks, 1964). Four types of residual plots are used for understanding the fits (Figure 4.1).

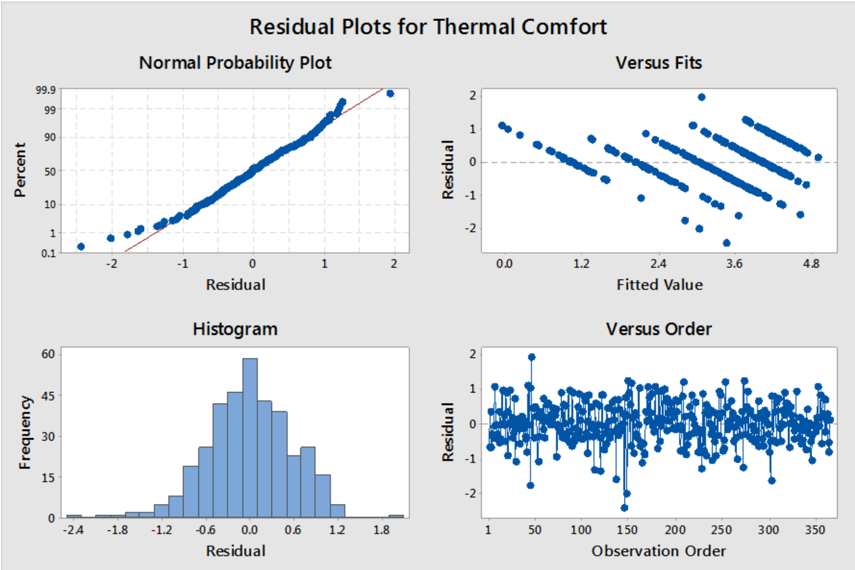


Figure 4.1 - Residual Plots - Thermal Comfort

4.2.3.1 Normal Probability Plot

Normal probability presents the residuals versus their expected values. Higher the plot follows the main line, higher the normal distribution. The figure below indicates that the residuals are normally distributed.

4.2.3.2 Versus Fits Plot of Fitted Values

Residual versus fits show that the variance of the residual decreases as the value of the fits increases. The scatter of the residuals becomes closer as the value of the fits increases. This pattern indicates that the variances of the residuals are unequal.

4.2.3.3Residual Histogram Plot

The residual histogram is used to identify the skewness of the data. A U-shaped histogram indicates the normal distribution of the data. Above diagram is U-shaped, it indicates that this is a normal distribution of the data.

4.2.3.4Residual Versus Order Plot

The residual versus order plot is used to determine whether there any dependency between the residuals. The residuals in the below plot are in between -1 and 1 but do not suggest any pattern. It indicates that regression assumptions are satisfied.

Overall, residual plots support the coefficient of determination by indicating that the fit of the model is good, and regression assumptions are satisfied.

4.2.4 Regression Equation

The regression equation is an outcome of the response surface analysis. It presents the statistical relationship between input (independent) variables and the output (dependent) variables.

Thermal Comfort = -52.08 + 5.666 Temperature - 0.1318 Relative Humidity
- 0.015 Outside temperature - 0.0836 Outside Relative Humidity
+ 0.00637 CO2 - 0.2088 Sound - 0.00460 Light - 0.0468 VOC
+ 1.53 Kind of Workspace_1 + 1.536 Kind of Workspace_2
+ 2.79 Kind of Workspace_3 - 6.17 Kind of Workspace_4
+ 0.32 Kind of Workspace_5 + 0.37 Do you sit near (wall type):_1
+ 0.424 Do you sit near (wall type):_2
- 0.484 Do you sit near (wall type):_3
- 0.307 Do you sit near (wall type):_4 - 0.11728 Temperature*Temperature
+ 0.000460 Relative Humidity*Relative Humidity
- 0.003066 Outside temperature*Outside temperature
+ 0.000363 Outside Relative Humidity*Outside Relative Humidity
- 0.000270 Temperature*CO2
+ 0.001846 Relative Humidity*Outside temperature
- 0.0381 Relative Humidity*Do you sit near (wall type):_1
+ 0.01842 Relative Humidity*Do you sit near (wall type):_2
+ 0.01876 Relative Humidity*Do you sit near (wall type):_3
+ 0.00094 Relative Humidity*Do you sit near (wall type):_4
+ 0.00313 Outside temperature*Sound
- 0.0217 Outside temperature*Kind of Workspace_1
- 0.0252 Outside temperature*Kind of Workspace_2
+ 0.0074 Outside temperature*Kind of Workspace_3
+ 0.1010 Outside temperature*Kind of Workspace_4
- 0.0614 Outside temperature*Kind of Workspace_5
+ 0.001164 Outside Relative Humidity*Sound
+ 0.000838 CO2*Kind of Workspace_1 -
0.001454 CO2*Kind of Workspace_2
+ 0.001355 CO2*Kind of Workspace_3 -
0.00248 CO2*Kind of Workspace_4
+ 0.00174 CO2*Kind of Workspace_5 + 0.000736 Sound*VOC
- 0.0246 Sound*Kind of Workspace_1
+ 0.0055 Sound*Kind of Workspace_2
- 0.0562 Sound*Kind of Workspace_3
+ 0.0600 Sound*Kind of Workspace_4
+ 0.0154 Sound*Kind of Workspace_5 + 0.000073 Light*VOC
- 0.00044 Light*Kind of Workspace_1
+ 0.00107 Light*Kind of Workspace_2
- 0.00290 Light*Kind of Workspace_3
+ 0.00376 Light*Kind of Workspace_4
- 0.00150 Light*Kind of Workspace_5
+ 0.0293 VOC*Do you sit near (wall type):_1
- 0.02088 VOC*Do you sit near (wall type):_2
- 0.00733 VOC*Do you sit near (wall type):_3
- 0.00107 VOC*Do you sit near (wall type):_4

4.2.4.1 Equation Explanation

Regression equation explains the effect of the independent variable (temperature, relative humidity, outside temperature, outside relative humidity etc.) on the dependent variable (thermal comfort). The equation includes input variables with a p-value higher than 0.01. These variables include sound and type of workspace. Removing these variables led to a decrease in R-value of the equation. While these variables contribute to the overall equation, they do not have any direct impact on the output variable.

In this equation, - 52.08 is the intercept (constant). Regression equation shows that thermal comfort depends on the temperature. When temperature increases by one-degree Celsius, thermal comfort increase in 5.666 times. Similarly, when relative humidity increases by one-degree Celsius, thermal comfort decreases in 0.1318 times.
There are also quadratic dependencies such as a 0.11728 Temperature*Temperature. Hence, when the temperature increases by one unit, the thermal comfort increases to 5.666 times, minus a 0.11728 Temperature*Temperature.

As part of the analysis, Minitab produces various types of graphs and plots that show various relationships and impact between the independent and dependent variables.

4.2.5 Pareto Chart

Pareto charts are used to describe the effect of the independent variables on the dependent variable (Figure 4.2). It highlights the magnitude of variability in the dependent variable caused by any variation in the independent variable. It plots the absolute value of the magnitude of impact. Redline is a reference line set at 1.65 on the chart. This means that any variable with more than 1.65 value has a significant effect on the input variable.

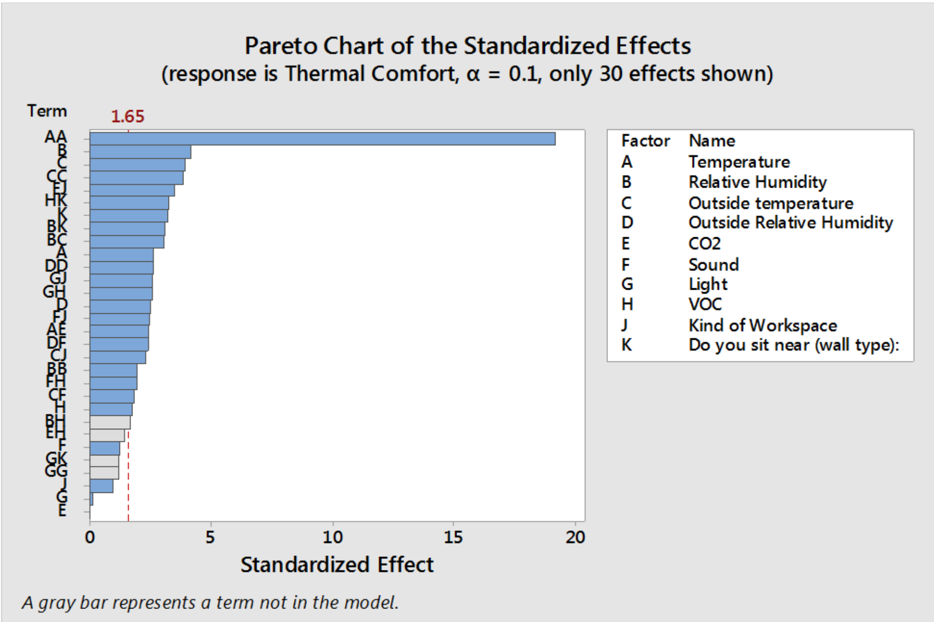


Figure 4.2 - Pareto Chart - Thermal Comfort

The following variables affect occupant productivity:

1. Temperature*Temperature (highest impact)
2. Relative humidity
3. Outside temperature*Outside temperature
4. CO^{2}*Kind of workspace
5. VOC*Wall type
6. Wall type

7. Relative Humidity*Wall type
8. Relative Humidity*Outside Temperature
9. Temperature
10. Outside Relative Humidity*Outside Relative Humidity

4.2.6 Contour and Surface Plots

Contour and surface plots are used to show the effect of two independent variables (predictor variables) on the response variable (dependent). They are used to identify optimal results. Contour plots are used to show the variation of response in detail to outline the optimum response. Whereas, surface plots are used to show the overall profile of the response as per the variations of independent variables (Myers et al., 2016).

In this experiment, factors with a p-value lower than 0.1 have been considered for analysis:

4.2.6.1 Effect of Light and Carbon Dioxide on Thermal Comfort and its impact on Occupant Productivity

Below plots describe the effect of light and carbon dioxide on occupant thermal comfort and its impact on productivity. Plots are measured at typical hold values of various independent variables. It highlights the following:

- It shows that carbon dioxide has a direct effect on occupant response, which influences occupant thermal comfort.
- Temperature is at 23.61°c, which is the optimum occupant productivity temperature. However, it is observed that variation in carbon dioxide

leads to change in occupant response to thermal comfort's effect on occupant productivity.

- Plots below indicate a positive correlation between light and thermal comfort's effect on productivity (Figure 4.3, Figure 4.4). It also outlines that Lux levels influence an occupant's perception of thermal comfort.

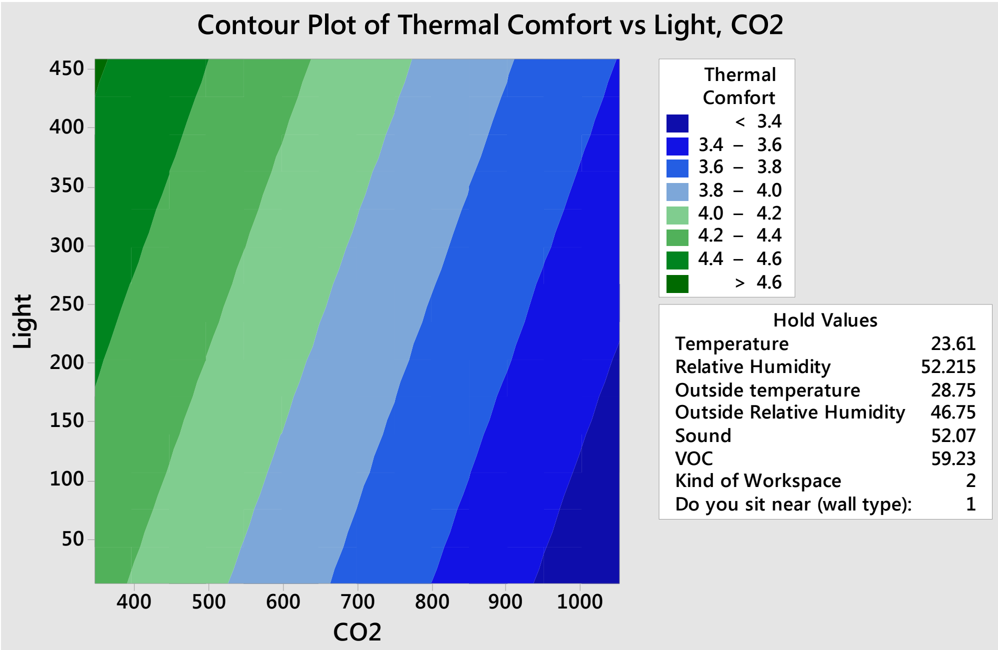


Figure 4.3 - Contour Plot – Effect of Light and Carbon Dioxide on Thermal comfort

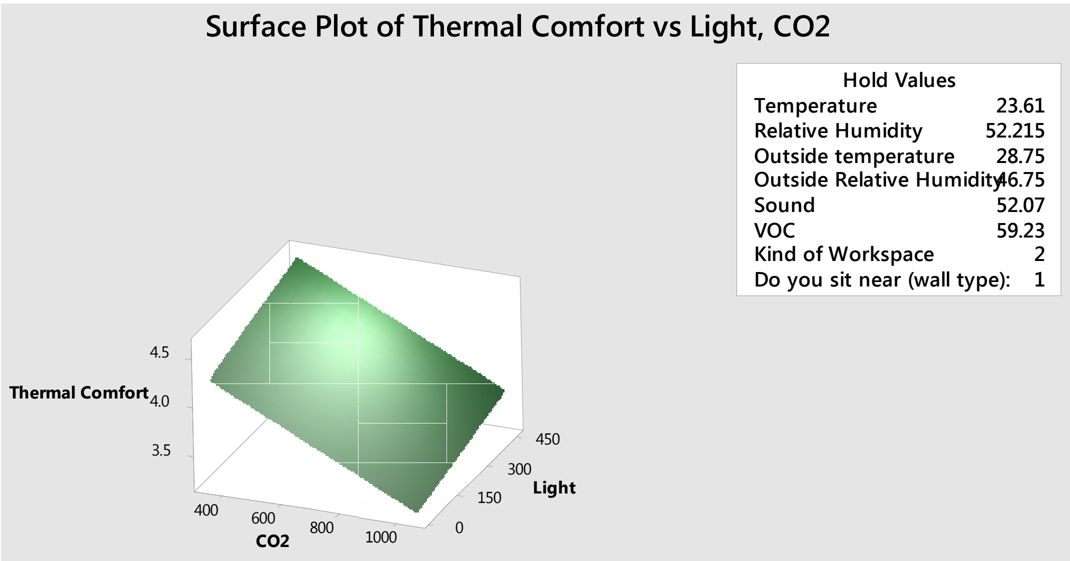


Figure 4.4 Surface Plot - Effect of Light and Carbon Dioxide on Thermal Comfort

4.2.6.2 Effect of VOC, Outside Relative Humidity on Thermal Comfort and its impact on Occupant Productivity

The plots below represent the effect of VOC and the outside relative humidity on occupant thermal comfort and productivity (Figure 4.5, Figure - 4.6). Plots are measured at typical hold values of various independent variables. As per the existing literature, the overall comfort level goes down as the VOC level increases (Panagiotaras et al., 2013). This analysis also indicates a positive relationship between occupant thermal comfort, productivity and VOC free air (VOC free air by percentage). It suggests that when VOC free air is above 85%, it has a positive effect on thermal comfort and productivity.

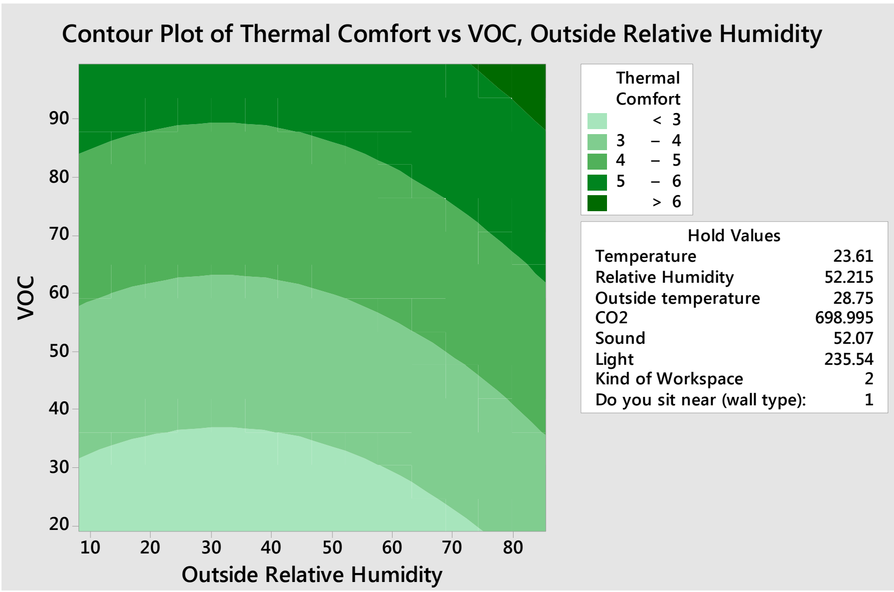


Figure 4.5 - Contour Plot - Effect of VOC and Outside R.H on Thermal Comfort

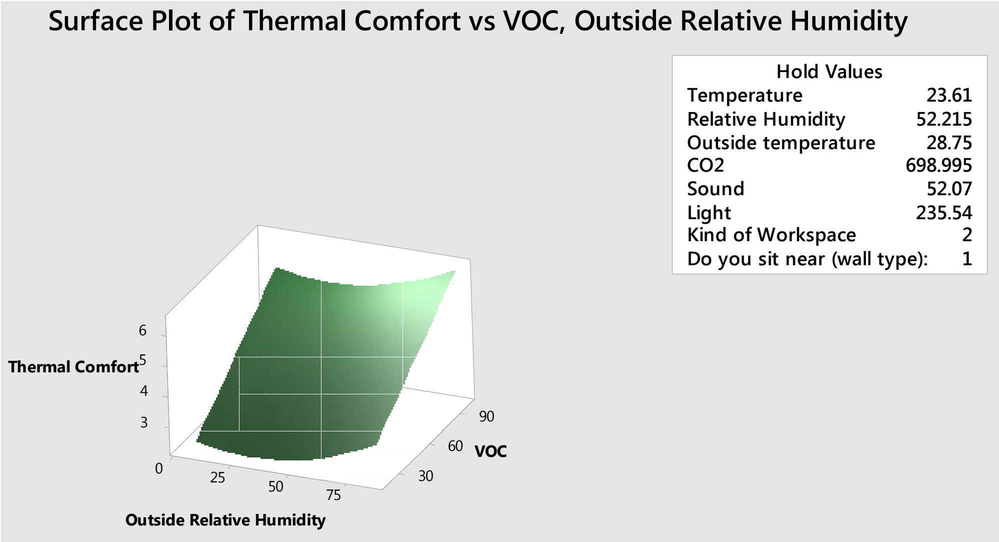


Figure - 4.6 - Surface Plot - Effect of VOC & Outside RH on Thermal Comfort

4.2.6.3 Thermal Comfort vs Light, Outside Relative Humidity on Thermal Comfort and its Impact on Occupant Productivity

The plots below represent the effect of light and outside relative humidity on occupant thermal comfort and its impact on productivity (Figure 4.7, Figure 4.8). Plots are measured at typical hold values of various independent variables. They indicate that the outdoor relative humidity between 20-60% negatively impacts occupant productivity. As per the observations, this low-level humidity is during Qatar's summer-time peak. It shows that when low outside humidity and high outside temperature combined with low indoor temperature, it creates a temperature difference between the indoor and outdoor environment. It is observed that when there is this temperature difference, combined with low Lux levels, it leads to a negative impact on thermal comfort and productivity.

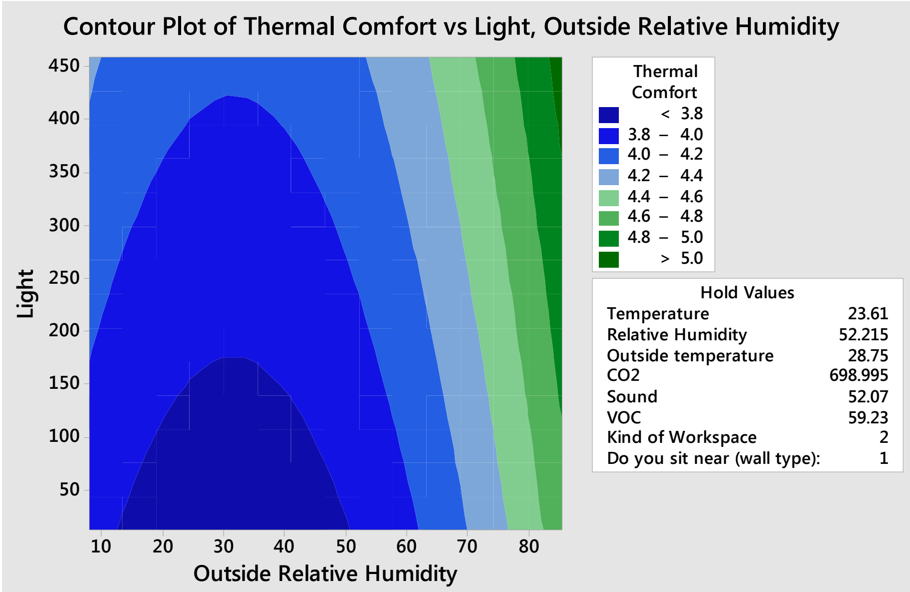


Figure 4.7 - Contour Plot - Effect of Light and Outside RH on Thermal Comfort

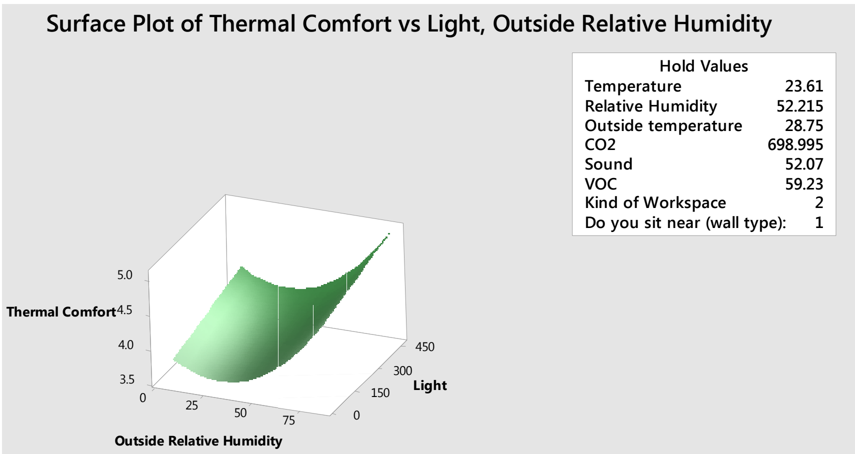


Figure 4.8 - Surface Plot –Effect of Light and Outside RH on Thermal Comfort

4.2.6.4 Effect of Sound and Outside Relative Humidity on Thermal Comfort and its Impact on Occupant Productivity

The chart below shows the effect of sound and outside relative humidity on occupant thermal comfort and its impact on productivity (Figure 4.9, Figure 4.10). They indicate that sound has a stronger influence, as compared to outside relative humidity on thermal comfort. It shows that occupant response is positive up to 60 dB, highlighting that sound influences the occupant's perception of thermal comfort and their productivity.

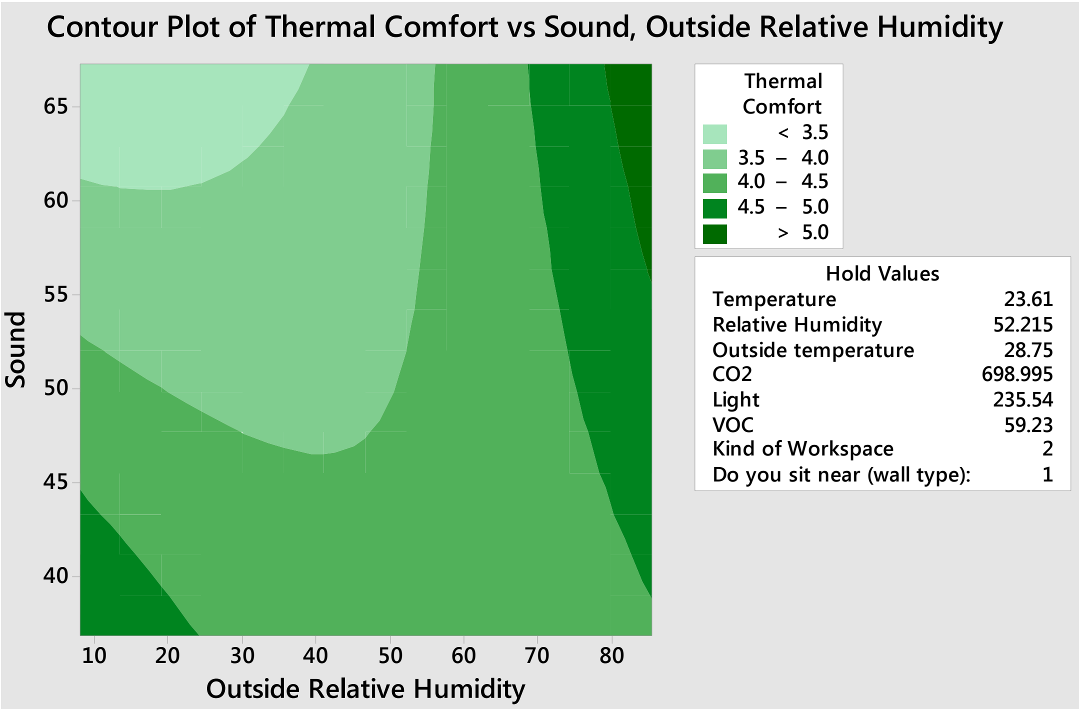


Figure 4.9 - Contour Plot - Effect of Sound and Outside R.H on Thermal Comfort

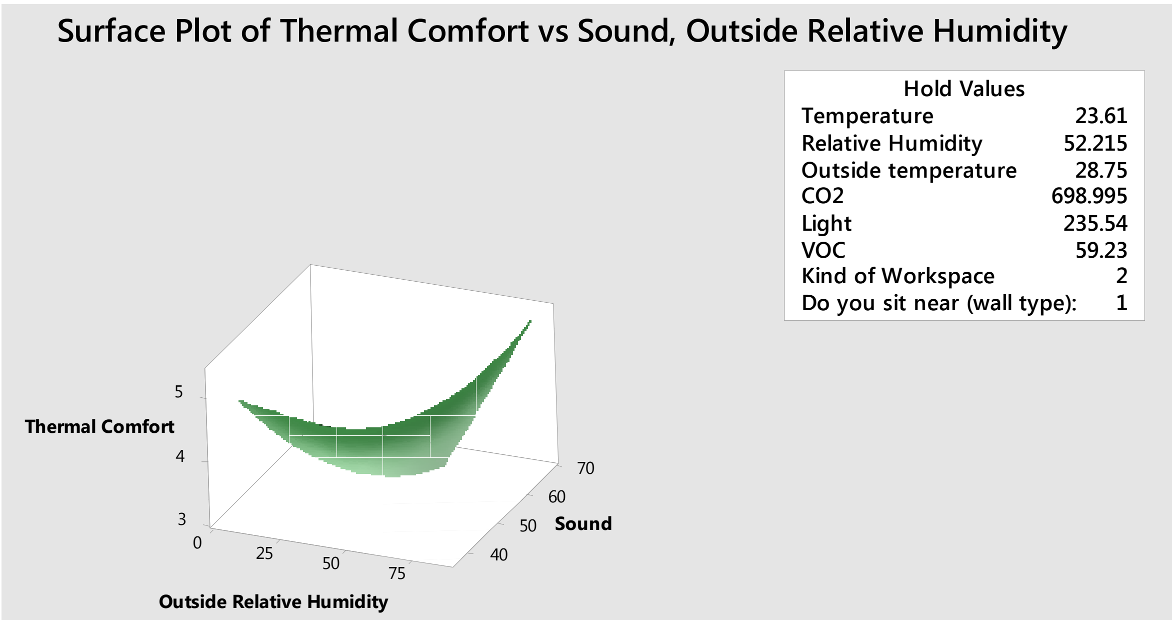


Figure 4.10 - Surface Plot - Effect of Sound and Outside R.H. on Thermal Comfort

4.2.6.5 Effect of Carbon Dioxide and Outside Relative Humidity on Thermal Comfort and its impact on Occupant Productivity

This chart highlights the effect of carbon dioxide and outside relative humidity on occupant thermal comfort and its impact on productivity (Figure 4.11, Figure 4.12). The plots indicate that carbon dioxide has a more prominent effect on productivity than outside relative humidity. Optimum productivity is observed around 400-700 ppm of carbon dioxide.

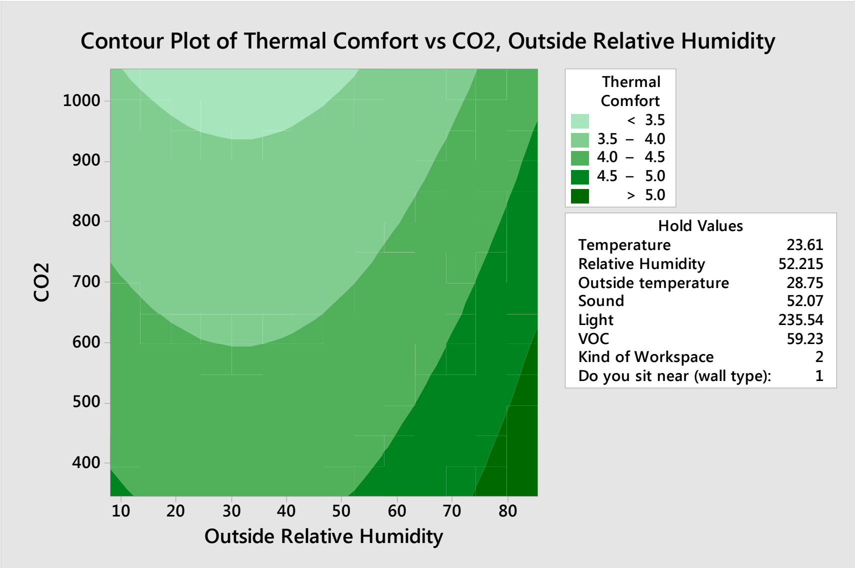


Figure 4.11 Contour Plot - Effect of Carbon Dioxide and Outside R.H on Thermal Comfort

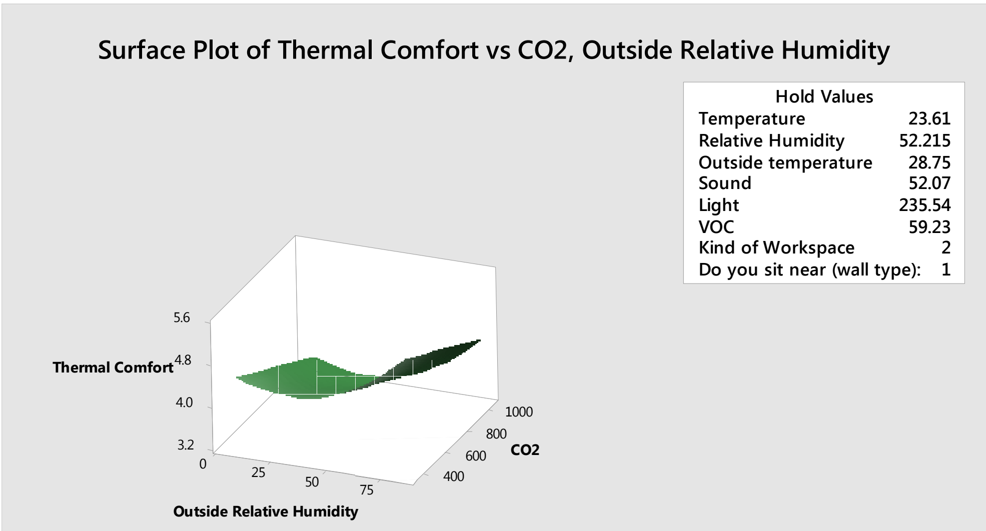


Figure 4.12 - Surface Plot - Effect of Carbon Dioxide and Outside R.H on Thermal Comfort

4.2.6.6 Effect of Light and Outside Temperature on Occupant's Thermal Comfort and its impact on Productivity

These charted plots demonstrate the impact of light and outside temperature on occupant productivity (Figure 4.13, Figure 4.14). It indicates that occupants prefer a minimum of 150 Lux levels. The outside temperature positively impacts occupant productivity in the range of 30 - 45°c. It is in conjunction with the indoor temperature at 23.61°c, indicating that occupants prefer to work in a colder environment rather than a hotter environment when compared to the outside temperature/environment.

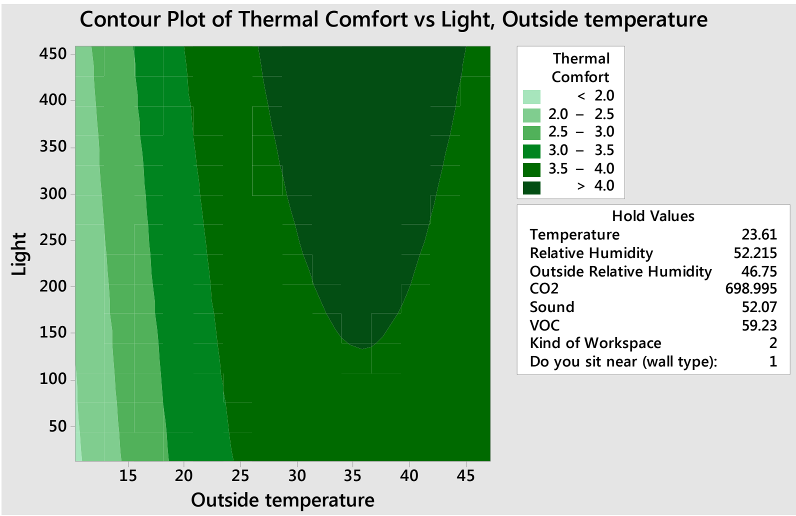


Figure 4.13 - Contour Plot - Effect of Light and outside Temperature on Thermal Comfort

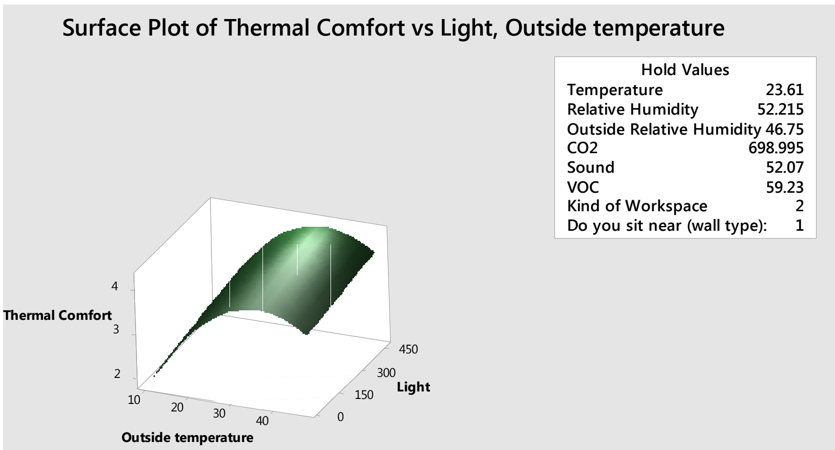


Figure 4.14 - Surface Plot - Effect of Light and Outside Temperature on Thermal Comfort

4.2.6.7 Effect of Sound and Outside Temperature on Thermal Comfort and Occupant Productivity

The following chart shows the effect of sound and outside temperature on occupant productivity (Figure 4.15, Figure 4.16). It is observed that sound has the opposite effect on occupant productivity. Sound also influences the occupant's reaction to the outside temperature. A shift in optimum productivity range from 20-35°c to 30-45°c can be observed when there is an increase in sound levels. It shows that sound has a more prominent impact on productivity than the outside temperature.

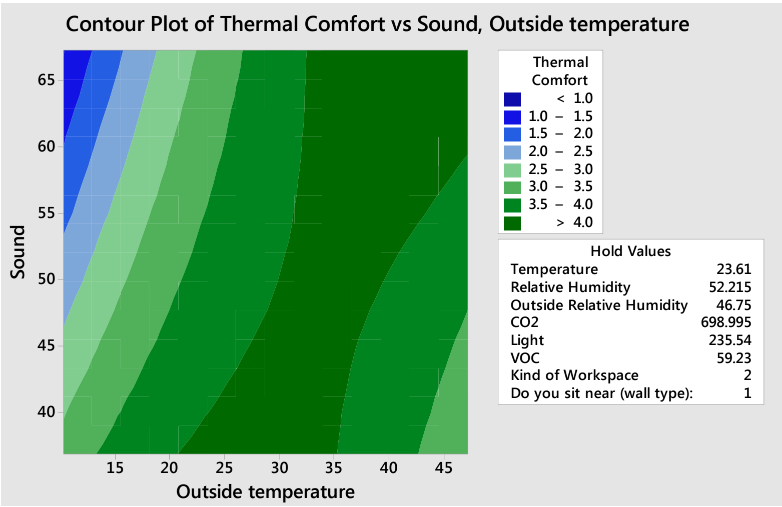


Figure 4.15 - Contour Plot - Effect of Sound and Outside Temperature on Thermal Comfort

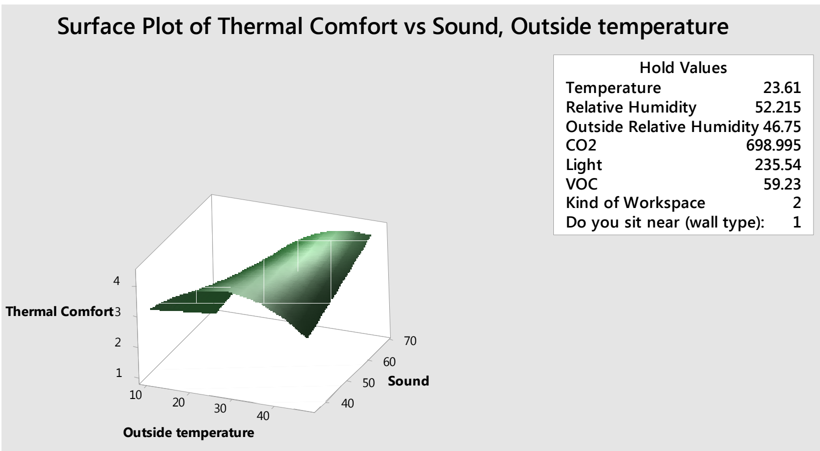


Figure 4.16 - Surface Plot - Effect of Sound and Outside Temperature on Thermal comfort

4.2.6.8 Effect of Carbon Dioxide and Outside Temperature on Thermal Comfort and Occupant Productivity

The charts below show the effect of carbon dioxide and outside temperature on occupant productivity (Figure 4.17, Figure 4.18). It can be seen that the highest level of productivity is achieved at 30-40°c with carbon dioxide below 400 ppm. Also, productivity is positive until 700 ppm of carbon dioxide and when outside temperature ranges from 22-45°c. It highlights that outside temperature has more effect on an occupant's thermal comfort and its impact on productivity as compared to carbon dioxide.

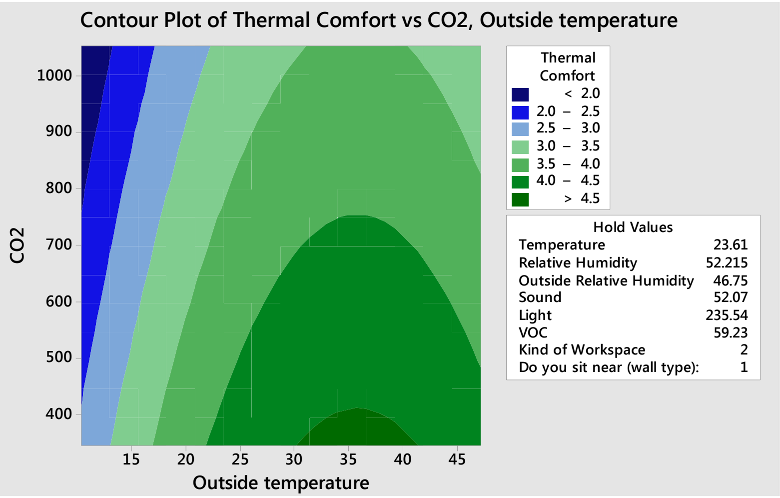


Figure 4.17 - Contour Plot - Effect of Carbon Dioxide and Outside Temperature on Thermal Comfort

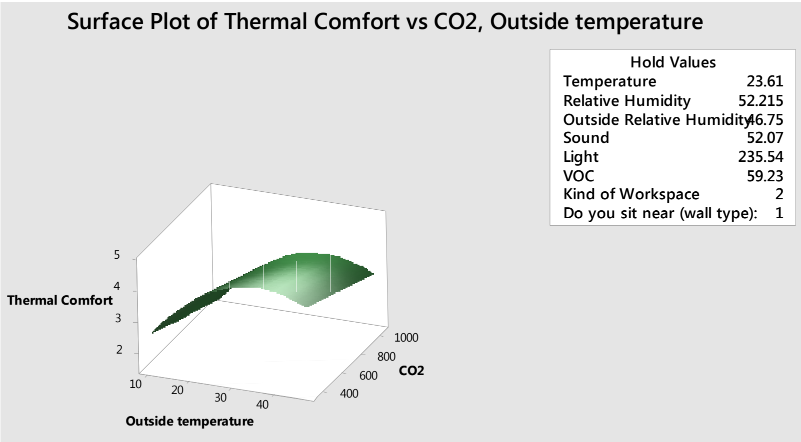


Figure 4.18 Surface Plot - Effect of Carbon Dioxide and Outside Temperature on Thermal Comfort

4.2.6.9 Effect of Light and Relative Humidity on Occupant comfort and Productivity

Here, the influence of light and relative humidity on occupant's thermal comfort and its impact on productivity is shown. These indicate that relative humidity has a positive impact on occupant thermal comfort and productivity, up to 65%. Plots also suggest that between light and relative humidity, light has no perceivable impact on occupant productivity.

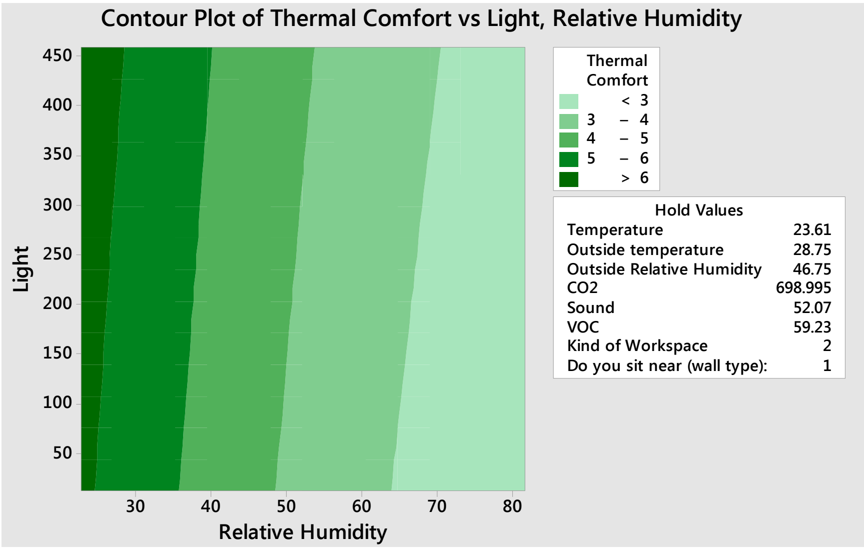


Figure 4.19 – Contour Plot - Effect of Light and Relative Humidity on Thermal Comfort

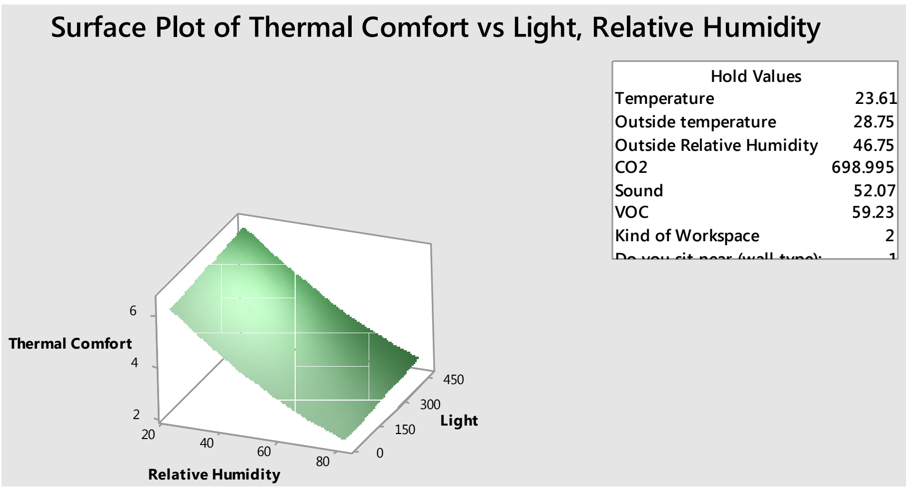


Figure 4.20 – Surface Plot - Effect of Light and Relative Humidity on Thermal Comfort

4.2.6.10 Effect of Light and Relative Humidity on Thermal Comfort and its impact on Occupant Productivity

These charts highlight the effect of light and relative humidity on thermal comfort and its impact on occupant productivity (Figure 4.21, Figure 4.22). They show that relative humidity has a positive impact up until 70%, but the sound has no perceivable impact on occupant comfort and productivity. It should be considered that these effects are observed while other indoor environment factors kept at hold values.

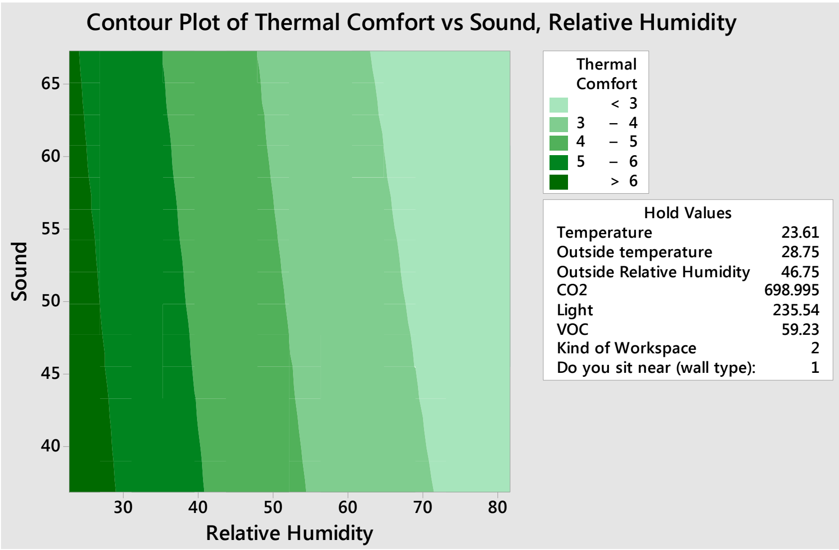


Figure 4.21 - Contour Plot - Effect of Sound and Relative Humidity on Thermal Comfort

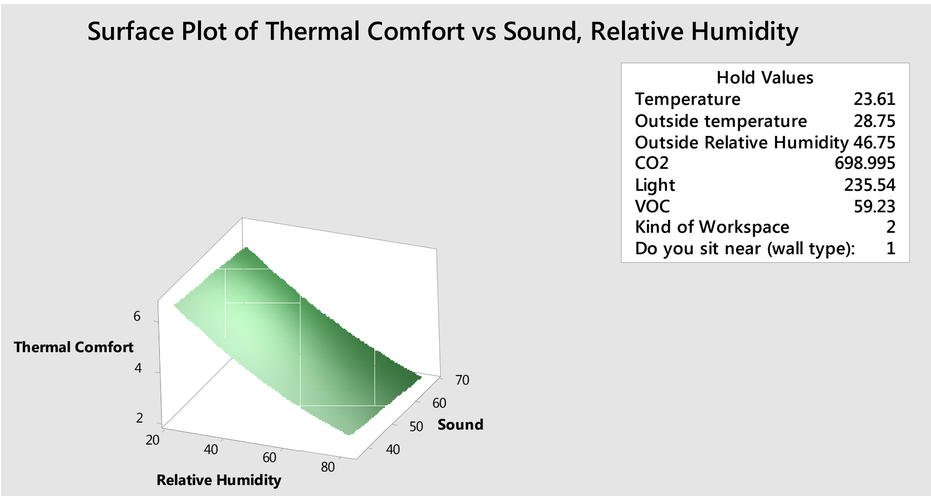


Figure 4.22 - Surface Plot - Effect of Sound and Relative Humidity on Thermal Comfort

4.2.6.11 Effect of Carbon Dioxide and Relative Humidity on Thermal Comfort and Occupant Productivity

The plots below highlight the effect of carbon dioxide and relative humidity on thermal comfort and their impact on the occupant productivity (Figure 4.23, Figure 4.24). Carbon dioxide does not affect thermal comfort. Relative humidity has a positive effect on an occupant's comfort levels up until 60%.

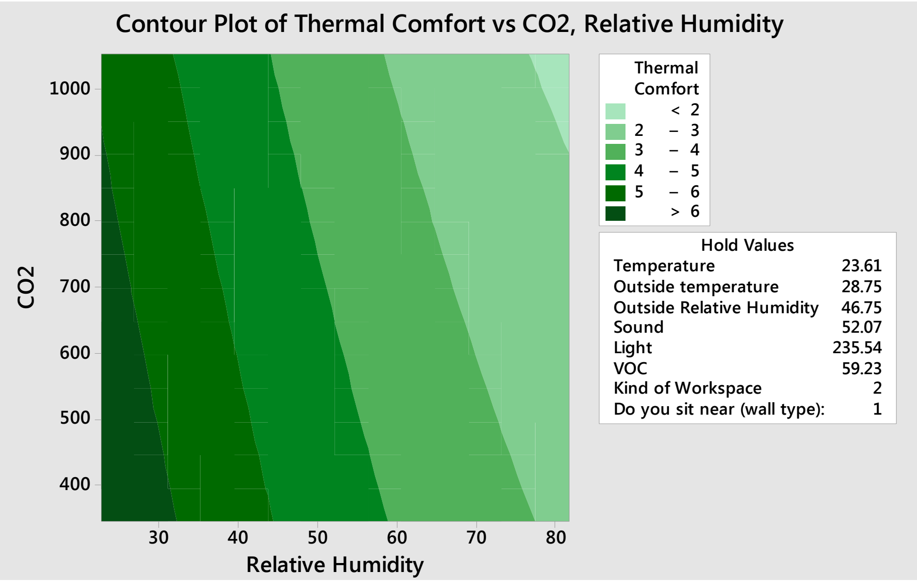


Figure 4.23 - Contour Plot - Effect of Carbon Dioxide and Relative Humidity on Thermal Comfort

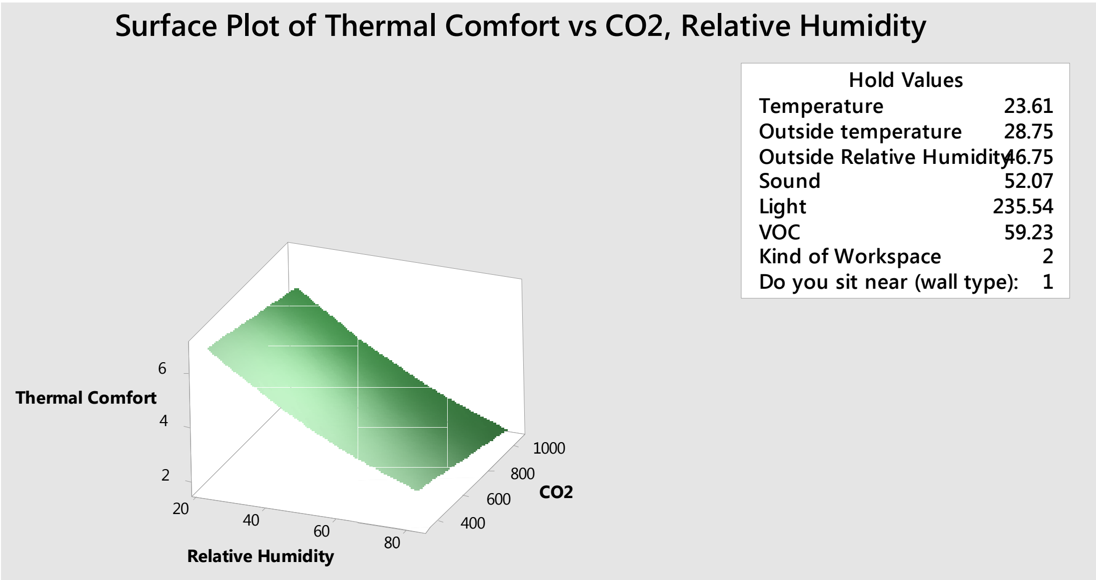


Figure 4.24 - Surface Plot - Effect of Carbon Dioxide and Relative Humidity on Thermal Comfort

4.2.6.12 Effect of Outside Relative Humidity and Relative Humidity (indoor) on Thermal Comfort and its impact on Occupant Productivity

The charts below indicate the effect of outside relative humidity and inside relative humidity on occupant thermal comfort and productivity (Figure 4.25, Figure 4.26). They outline that relative humidity (indoor) has a positive impact up until 55%, but show no impact from 55%-70% on occupants' thermal comfort and productivity. These results vary slightly from the current expected humidity range (30-70%). Current comfort ranges are set based on relative humidity changing, along with variation in temperature. In the case of the present study, the temperature is held at 23.61°c (optimum comfortable value) , and only relative humidity is changed in the analysis. It indicates that when the temperature is at the maximum comfortable position, the effect of relative humidity is inversely proportional.

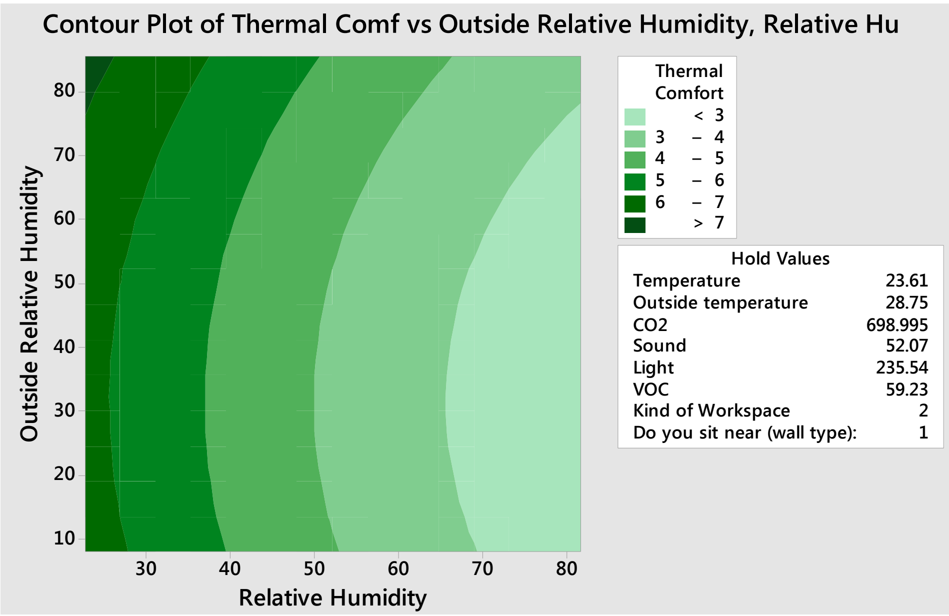


Figure 4.25 - Contour Plot - Effect of Outside R.H and Relative Humidity on Thermal Comfort

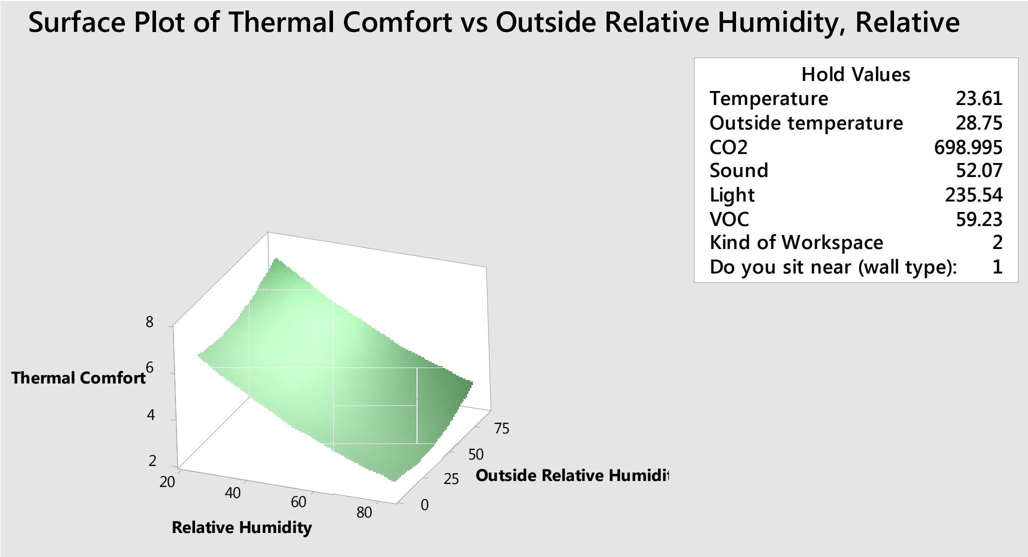


Figure 4.26 - Surface Plot - Effect of Outside R.H and Relative Humidity on Thermal Comfort

4.2.6.13 Effect of Temperature and VOC on Thermal Comfort and its impact on Occupant Productivity

Here, the effect of temperature and VOC on thermal comfort and its impact on occupant productivity has been highlighted through the use of charts (Figure 4.27, Figure 4.28). The plots highlight that temperature has a very positive effect on occupants when it ranges from 22-24.5 °c and a positive effect when it ranges from 21 - 25°c. While the VOC effect is influenced by temperature, plots indicate that it has a positive impact when VOC free air is above 65%. The optimum performance is observed at 22-24°c and above 90% (VOC free air).

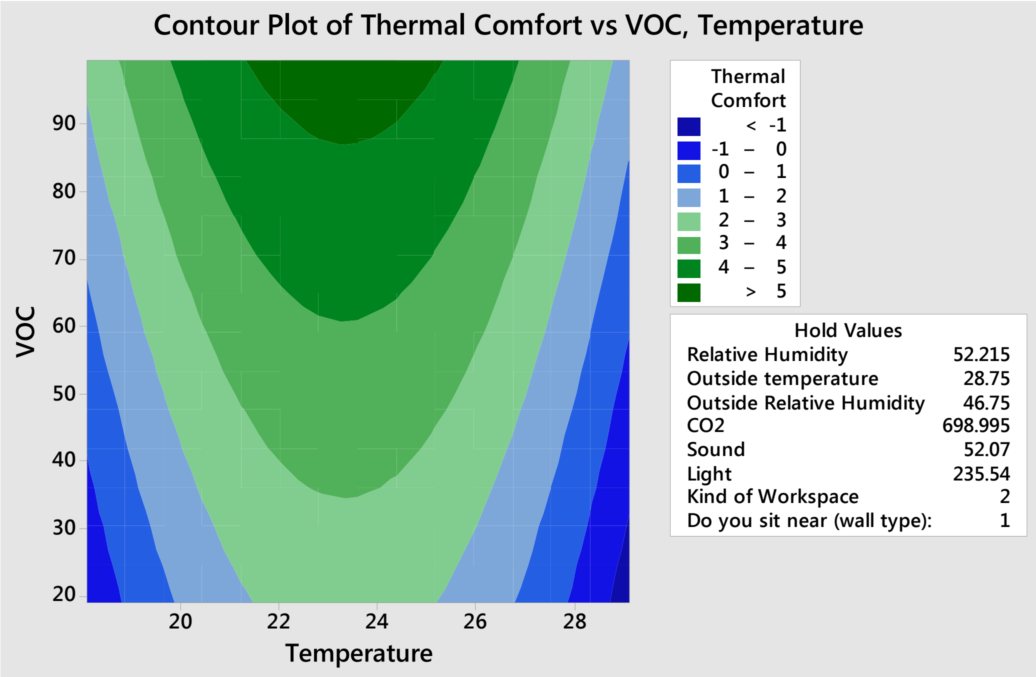


Figure 4.27 - Contour Plot - Effect of VOC and Temperature on Thermal Comfort

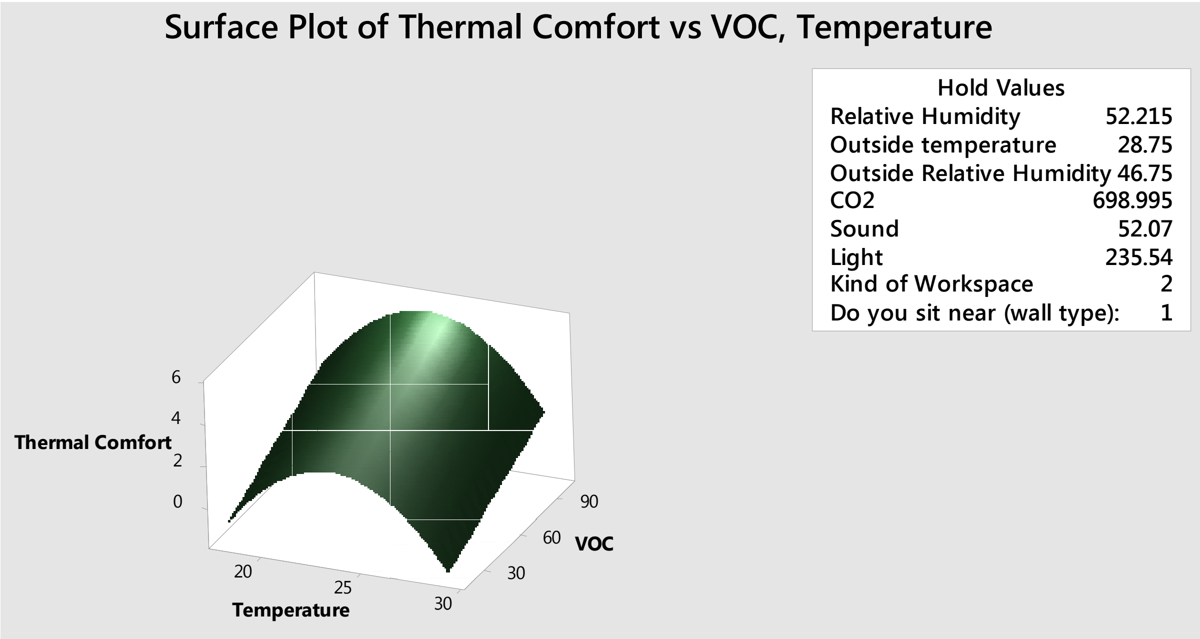


Figure 4.28 Surface Plot - Effect of VOC and Temperature on Thermal Comfort

4.2.6.14 Effect of Temperature and Light on Thermal Comfort and its impact on Occupant Productivity

These charts present the effect of VOC and temperature on thermal comfort and its impact on occupant productivity (Figure 4.29, Figure 4.30). They highlight that optimum productivity is achieved between 22-24°c and between 330-450 Lux levels.

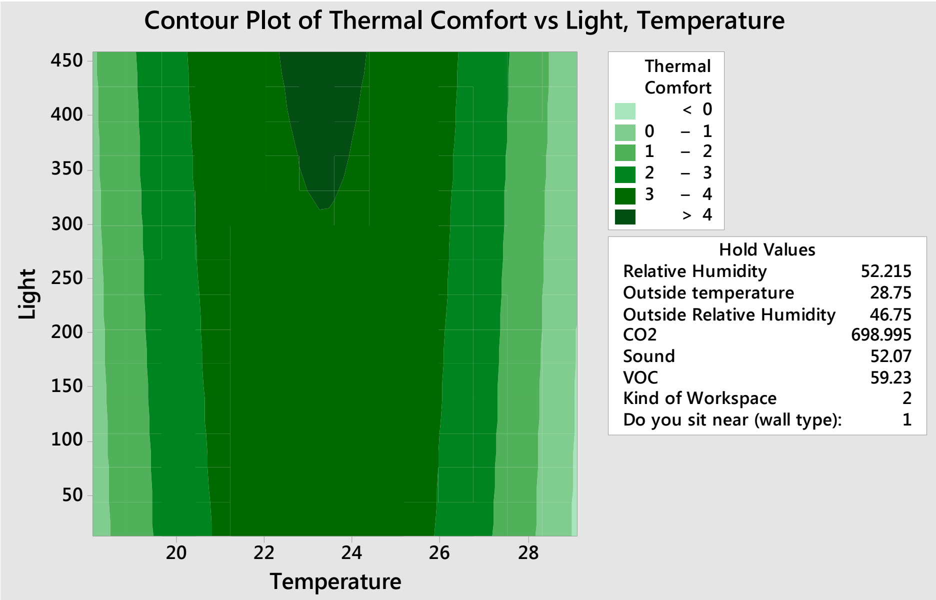


Figure 4.29 - Contour Plot - Effect of Light and Temperature on Thermal Comfort

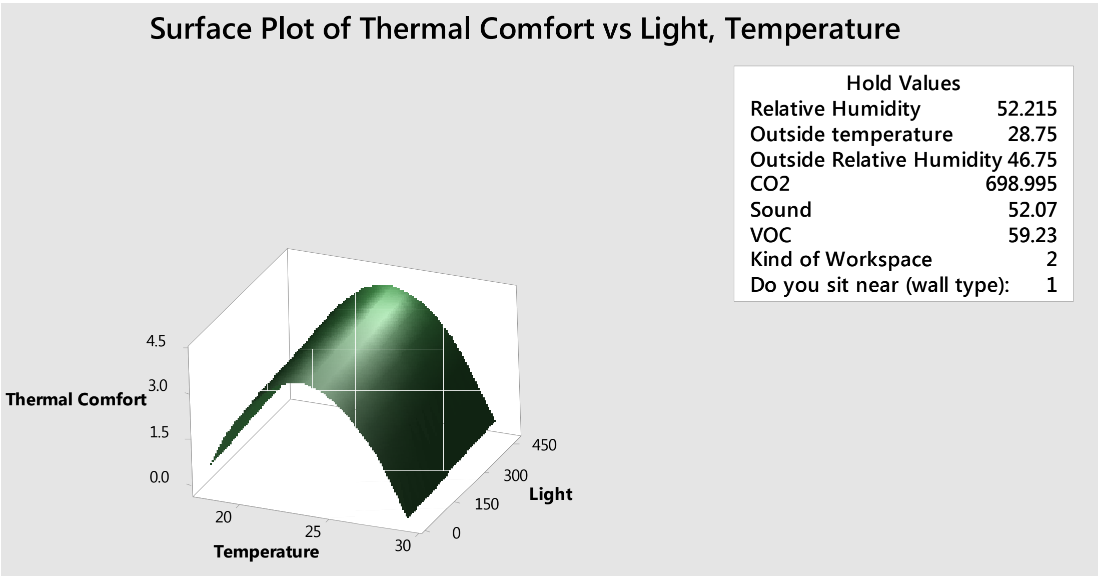


Figure 4.30 - Surface Plot - Effect of Light and Temperature on Thermal Comfort

4.2.6.15 Effect of Temperature and Sound on Thermal Comfort and its impact on Occupant Productivity

These plots show the effect of sound and temperature on occupant thermal comfort and its impact on productivity (Figure 4.31, Figure 4.32). It is highlighted that the highest level of productivity and thermal comfort is achievable between 22.5 – 24.5°c and below 48 dB levels.

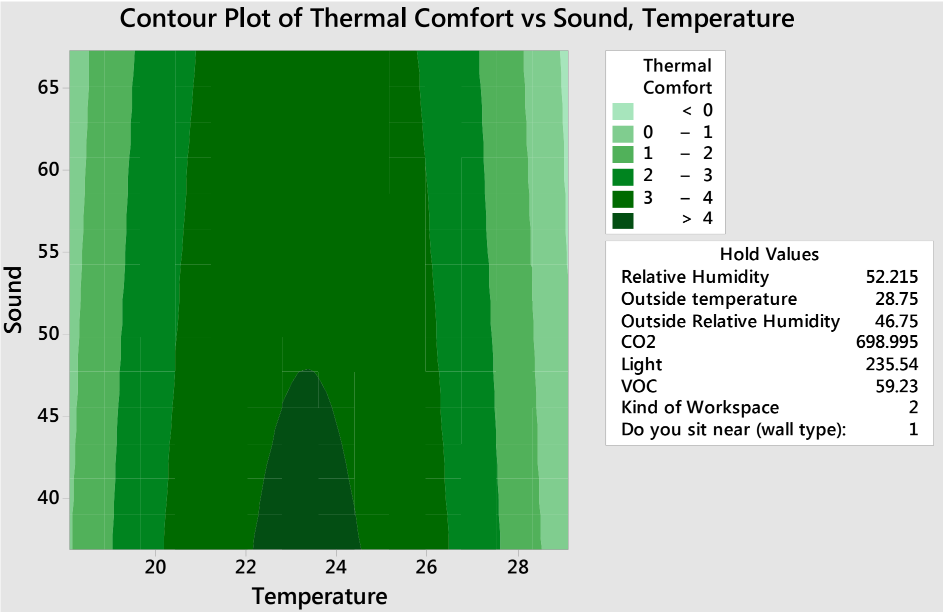


Figure 4.31- Contour Plot - Effect of Sound and Temperature on Thermal Comfort

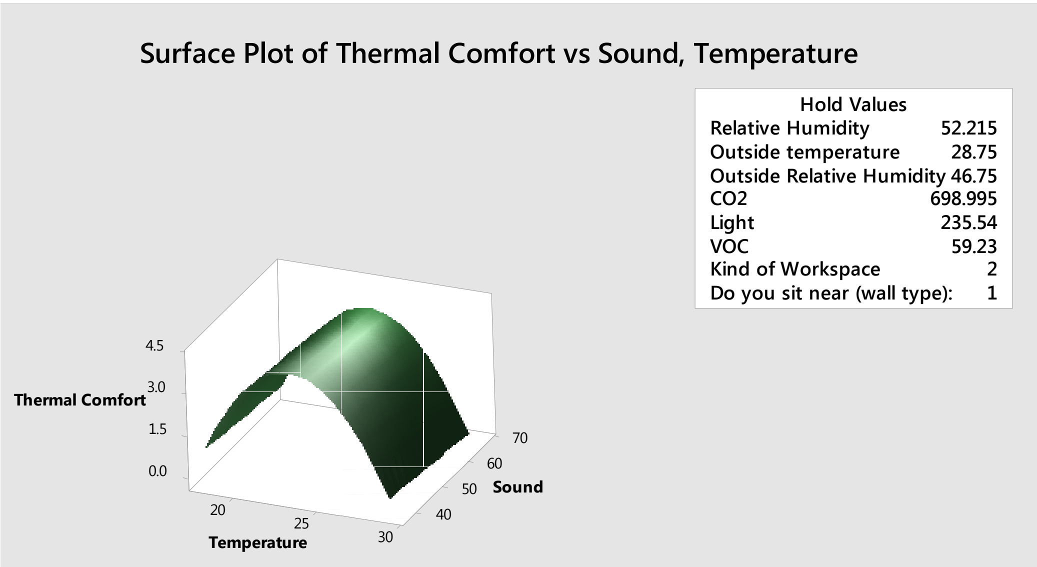


Figure 4.32 - Surface Plot - Effect of Sound and Temperature on Thermal Comfort

4.2.6.16 Effect of Temperature and Carbon Dioxide on Thermal Comfort and its impact Occupant Productivity

These plots show the effect of temperature and carbon dioxide on thermal comfort and its impact on occupant productivity (Figure 4.33, Figure 4.34). It is outlined that optimum productivity and thermal comfort is achieved when temperature ranges between 22-25°c and Carbon Dioxide levels below 650 ppm.

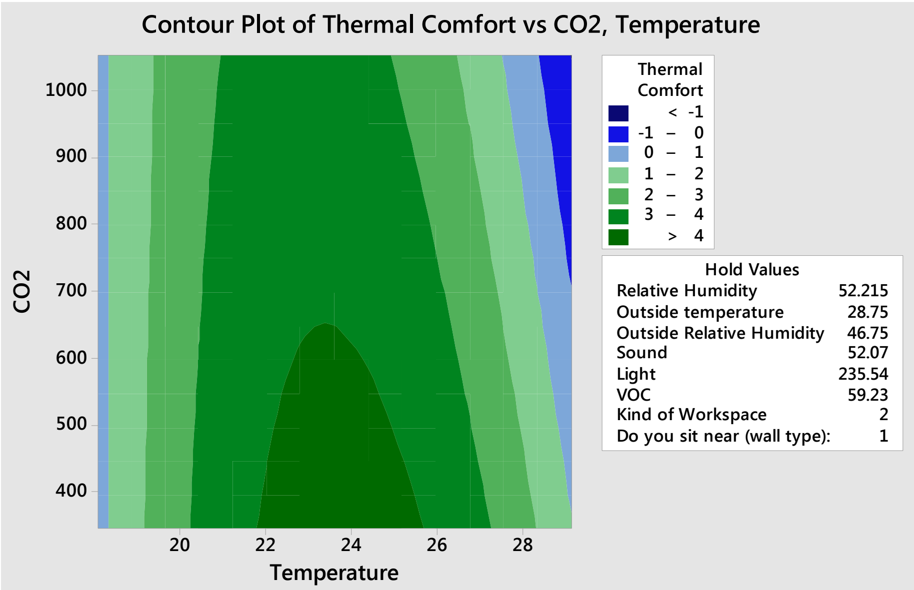


Figure 4.33 – Contour Plot - Effect of Temperature and Carbon Dioxide on Thermal Comfort

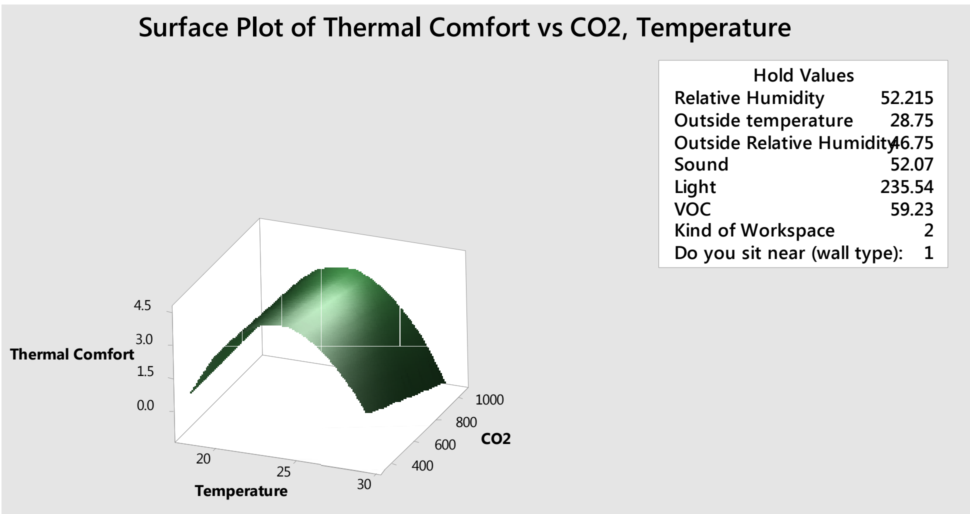


Figure 4.34 – Surface Plot - Effect of Temperature and Carbon Dioxide on Thermal Comfort

4.2.6.17 Effect of Outside Temperature and Temperature on Thermal Comfort and its impact on Occupant Productivity

Below is presented the effect of outside and inside temperature on thermal comfort and its impact on occupant productivity (Figure 4.35, Figure 4.36). The plots show that the highest level of thermal comfort and productivity is achievable when the temperature ranges between 21-24°c (indoor) and 30-40°c (outdoor).

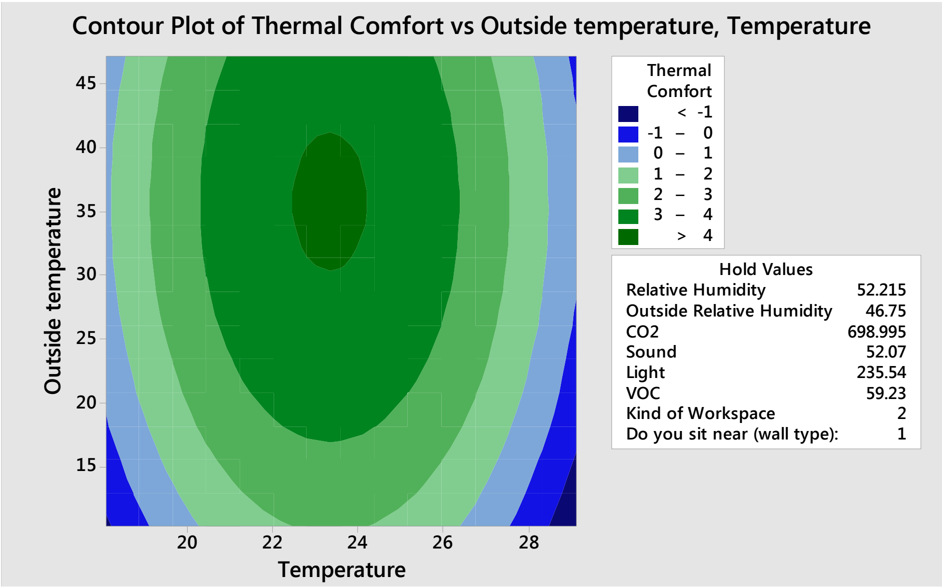


Figure 4.35 – Contour Plot - Effect of Outside Temperature and Temperature on Thermal Comfort

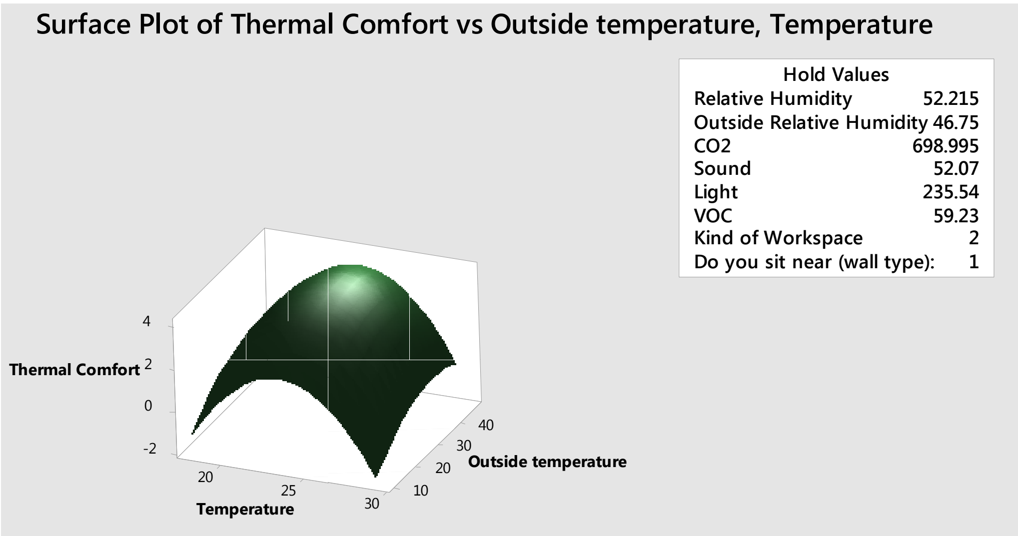


Figure 4.36 - Surface Plot - Effect of Outside Temperature and Temperature on Thermal Comfort

4.2.7 Summary of Results

This question was aimed to identify the influence of various physical parameters on an occupant's thermal comfort and their impact on productivity. The following are the primary results of the analysis:

1. Temperature, relative humidity, outside relative humidity, and VOC are the primary variables that influence thermal comfort and productivity. It is outlined by ANOVA and the main effect plot of thermal comfort.
2. Regression equation derived above can be used to determine the thermal comfort of an occupant in a similar geographical and climatic context.
3. Optimum levels (positive, very positive) of thermal comfort and productivity are observed at a temperature range of 21 - 24.5°c.
4. Lux level influences occupant's perception of thermal comfort. Low light levels make the occupant feel cold.
5. VOC influences the occupant's thermal comfort. Lower levels of VOC present in the air are associated with a higher level of thermal comfort and productivity.
6. Sound also influences an occupant's thermal comfort and its impact on occupant productivity. It has an inverse relationship with thermal comfort and productivity. Sound levels above 55dB are observed to have a negative impact on thermal comfort and productivity.

4.3 Response Surface Regression for Indoor Air Comfort (Natural Air) and Productivity

Response surface analysis of natural/fresh air was carried out to identify the input variables that influence occupant's perception of natural fresh air and how it affects their productivity. It produced the following:

- P-values for the independent factors their square and 2-way interactions
- R square (coefficient of determination)
- Residual Plots
- Regression equation
- Pareto Chart
- Contour plots
- Surface Plots
- Summary

4.3.1 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	50	387.070	7.7414	48.66	0.000
Linear	15	70.528	4.7018	29.55	0.000
CO2	1	45.278	45.277	284.60	0.000
VOC	1	1.936	1.9362	12.17	0.001
Relative Humidity	1	0.511	0.5107	3.21	0.074
Temperature	1	0.686	0.6860	4.31	0.039
Outside temperature	1	1.264	1.2636	7.94	0.005
Outside Relative Humidity	1	1.052	1.0518	6.61	0.011
Sound	1	0.355	0.3552	2.23	0.136
Light	1	0.135	0.1353	0.85	0.357
Kind of Workspace	4	2.436	0.6089	3.83	0.005
Do you sit near (wall type):	3	1.877	0.6258	3.93	0.009

Square	3	10.337	3.4458	21.66	0.000
CO2*CO2	1	10.271	10.271	64.56	0.000
Outside temperature*Outside temperature	1	0.530	0.5304	3.33	0.069
Sound*Sound	1	0.443	0.4428	2.78	0.096
2-Way Interaction	32	12.802	0.4001	2.51	0.000
CO2*Outside temperature	1	0.608	0.6083	3.82	0.051
CO2*Outside Relative Humidity	1	1.139	1.1389	7.16	0.008
VOC*Outside temperature	1	1.012	1.0119	6.36	0.012
VOC*Outside Relative Humidity	1	0.617	0.6173	3.88	0.050
VOC*Do you sit near (wall type):	3	1.525	0.5084	3.20	0.024
Relative Humidity*Do you sit near (wall type):	3	1.381	0.4604	2.89	0.035
Temperature*Kind of Workspace	4	2.625	0.6562	4.12	0.003
Outside temperature*Outside Relative Humidity	1	0.502	0.5017	3.15	0.077
Outside temperature*Light	1	0.480	0.4801	3.02	0.083
Outside temperature*Kind of Workspace	4	3.016	0.7540	4.74	0.001
Outside Relative Humidity*Kind of Workspace	4	2.446	0.6116	3.84	0.005
Sound*Kind of Workspace	4	1.558	0.3894	2.45	0.046
Light*Kind of Workspace	4	1.759	0.4398	2.76	0.028
Error	314	49.955	0.1591		
Lack-of-Fit	310	49.455	0.1595	1.28	0.463
Pure Error	4	0.500	0.1250		
Total	364	437.025			

Table 4.2 Analysis of Variance – Air Comfort (Natural Air)

The experiment was based on the following hypothesis,

- H_0 = Variable has no effect on occupant's indoor air comfort (natural air) and its impact on productivity.
- H_{alt} = Variable has an effect on occupant's indoor air comfort (natural air) and its impact on productivity.

The ANOVA is done using a=0.1.

If p-value ≥ 0.1, it indicates strong evidence of null hypothesis.

If p-value ≤ 0.1, it indicates strong evidence against the null hypothesis, hence rejecting the null hypothesis.

Based on the ANOVA, the following factors have an effect on occupant's air comfort (natural air) and its impact on the productivity of occupants (Table 4.2):

1. CO^2
2. VOC
3. Relative Humidity
4. Temperature
5. Outside temperature
6. Outside relative humidity
7. Kind of workspace
8. Do you sit near wall type
9. CO2*CO2
10. Outside temp*outside temp
11. Sound*Sound
12. CO2*Outside temperature
13. CO2*Outside Relative Humidity
14. VOC*Outside temperature
15. VOC*Outside Relative Humidity
16. VOC*Do you sit near (wall type)
17. Relative Humidity*Do you sit near (wall type)
18. Temperature*Kind of Workspace
19. Outside temperature*Outside Relative Humidity
20. Outside temperature*Light
21. Outside temperature*Kind of Workspace
22. Outside Relative Humidity*Kind of Workspace
23. Sound*Kind of Workspace

24. Light*Kind of Workspace

For the present study, it is considered that the above factors affect indoor air comfort both directly and indirectly. All these factors have a different magnitude of influence. The level of magnitude would be highlighted in Pareto charts.

4.3.2 The Coefficient of Determination (Multiple Correlation Coefficient)

Coefficient of determination (adjusted R-square) value is 86.75%. It indicates that 87% of the data fits the regression and there is a significant relationship between dependent and independent variables.

4.3.3 Residual Plots

Residual plots are used to determine the fit of model data (Figure 4.37).

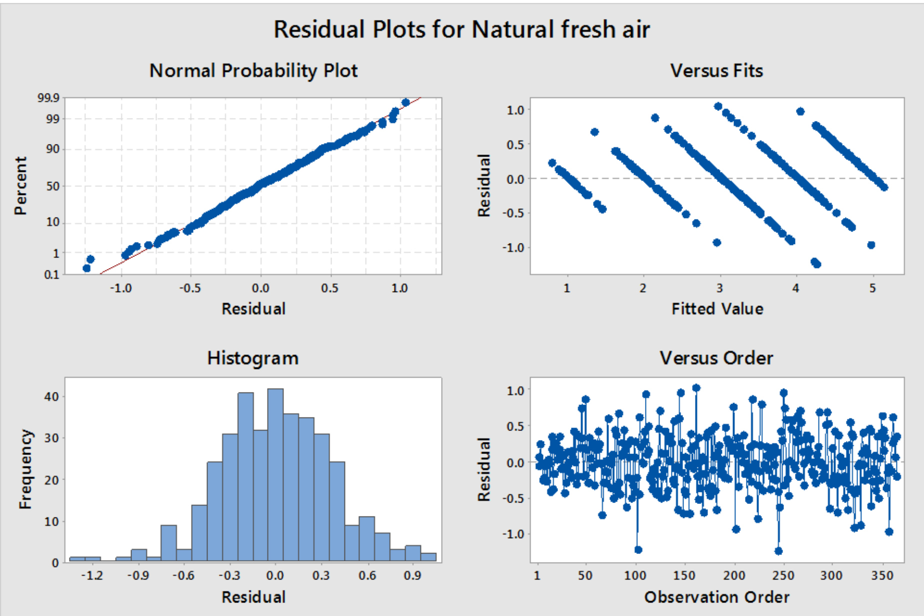


Figure 4.37 - Residual Plots for Natural Fresh Air

4.3.3.1 Normal probability plot

The residuals in the figure above follow the expected values (mainline). It indicates that residuals are normally distributed.

4.3.3.2 Versus fits of fitted value plot

The scatter of the residuals varies as the fitted value increases. It indicates that residuals are unequal.

4.3.3.3 Residual Histogram

Histogram figure above is observed to be closely shaped like a U- shaped histogram with few outliers. It indicates that the data is normally distributed.

4.3.3.4 Residual versus order plot

Residuals in the above figure are between -1 to 1 and suggest no pattern. It indicates that regression assumptions are satisfied.

4.3.4 Regression equation

Natural fresh air = -1.26 - 0.01210 CO2 + 0.0577 VOC - 0.0768 Temperature + 0.2483 Outside temperature + 0.0773 Outside Relative Humidity + 0.1024 Sound - 2.25 Kind of Workspace_1 + 0.95 Kind of Workspace_2 - 1.25 Kind of Workspace_3 - 1.16 Kind of Workspace_4 + 3.71 Kind of Workspace_5 + 0.167 Do you sit near (wall type):_1 + 0.230 Do you sit near (wall type):_2+ 0.064 Do you sit near (wall type):_3 - 0.460 Do you sit near (wall type):_4 + 0.01855 VOC*Do you sit near (wall type):_1 - 0.02564 Relative Humidity*Do you sit near (wall type):_1 + 0.1041 Temperature*Kind of Workspace_1+ 0.1213 Temperature*Kind of Workspace_2+ 0.0395 Temperature*Kind of Workspace_3+ 0.0914 Temperature*Kind of Workspace_4 - 0.356 Temperature*Kind of Workspace_5 - 0.0152 Outside temperature*Kind of Workspace_1- 0.0462 Outside temperature*Kind of Workspace_2

+ 0.0136 Outside temperature*Kind of Workspace_3
- 0.0214 Outside temperature*Kind of Workspace_4
+ 0.0691 Outside temperature*Kind of Workspace_5
- 0.01459 Outside Relative Humidity*Kind of Workspace_1
- 0.01438 Outside Relative Humidity*Kind of Workspace_2
+ 0.0259 Outside Relative Humidity*Kind of Workspace_5

4.3.4.1 Equation explanation

The regression equation shows various variables that affect occupant's indoor air comfort and its impact on productivity. It shows that carbon dioxide, VOC, temperature (both indoor and outdoor) and outside relative humidity do have an influence on an occupant's indoor air comfort and also impact on productivity. Along with the factors mentioned above, few more linear, square and interactions contribute to the final output.

As a part of the analysis, various types of graphs have been used to showcase the impact of different input variable on the output variable.

4.3.5 Pareto chart

A Pareto chart has been used to present the independent variable's magnitude of effect on the output variable. The chart has set 1.65 as the reference line to identify variables that influence an occupant's indoor air comfort and its impact on productivity (Figure 4.38).

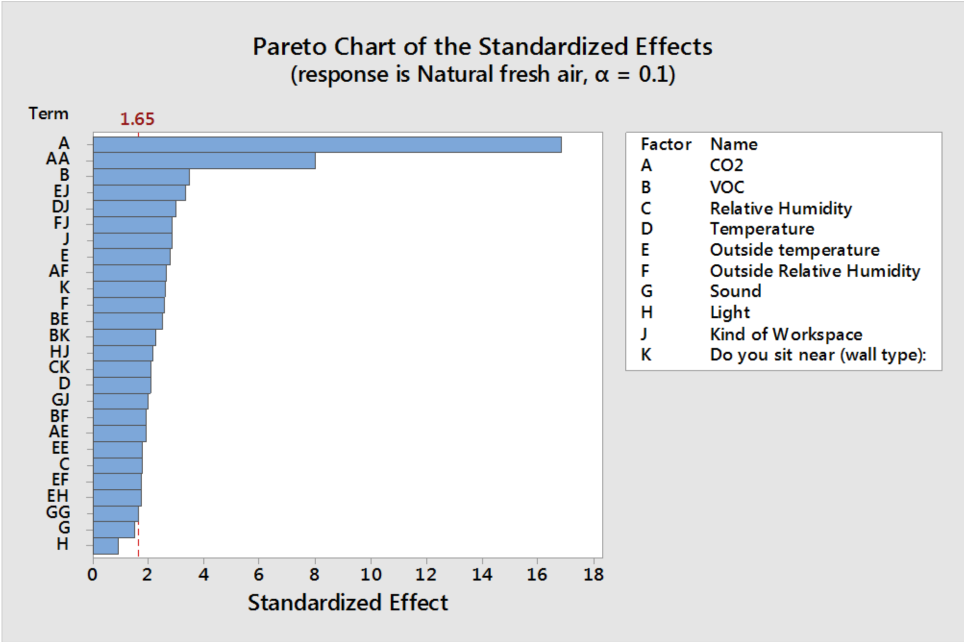


Figure 4.38 - Pareto Chart – Indoor Air Comfort (Natural Air)

Following variables have a significant effect:

1. Carbon Dioxide (maximum impact)
2. Carbon Dioxide*Carbon Dioxide
3. VOC
4. Outside Temperature*Kind of Workspace
5. Temperature*Kind of Workspace
6. Outside Relative Humidity*Kind of Workspace
7. Kind of Workspace
8. Outside Temperature
9. Carbon Dioxide*Outside Relative Humidity
10. Wall Type
11. Outside Relative Humidity

4.3.6 Contour and Surface Plots

Contour and surface plots are used to identify optimal results by showing the effect of two independent variables on the dependent variable. The researcher has only discussed the plots that show significant impacts or results on indoor air comfort and how it impact on productivity.

4.3.6.1 Effect of Light, VOC on Indoor Air Comfort (Natural Air) and its impact on Productivity

The charts below represent the effect of light and VOC on occupant's indoor air comfort and its impact on productivity (Figure 4.39, Figure 4.40). The plots highlight that VOC has a significant impact on occupant indoor air comfort (natural air) and productivity. Optimum range for VOC free air is achieved above 85%. Sound does not have any indicative effect on air comfort (natural air) and productivity.

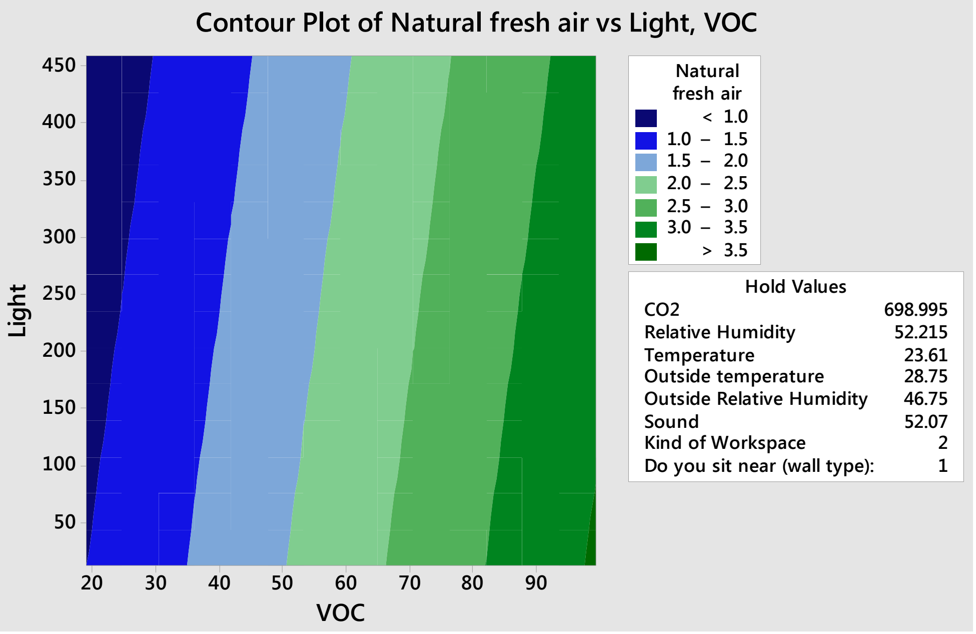


Figure 4.39 Contour Plot - Effect of Light and VOC on Air Comfort (Natural Air)

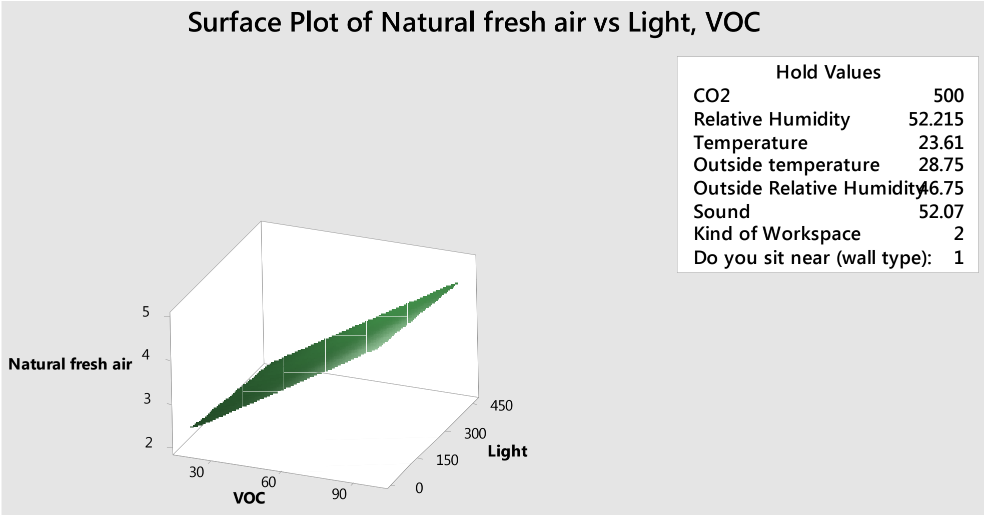


Figure 4.40 - Surface Plot - Effect of Light and VOC on Air Comfort (Natural Air)

4.3.6.2 Effect of Sound, VOC on Indoor Air Comfort (Natural Air) and its impact on Occupant Productivity

The charts below present the effect of sound and VOC on indoor air comfort (natural air) and its impact on occupant productivity (Figure 4.41, Figure 4.42). Both contour and surface plot indicates that VOC free air (percentage) have a positive relationship with indoor air comfort (natural air) and its impact on productivity. As a percentage of VOC free air increases, comfort and productivity also increase. There is no noticeable effect of sound on indoor air comfort.

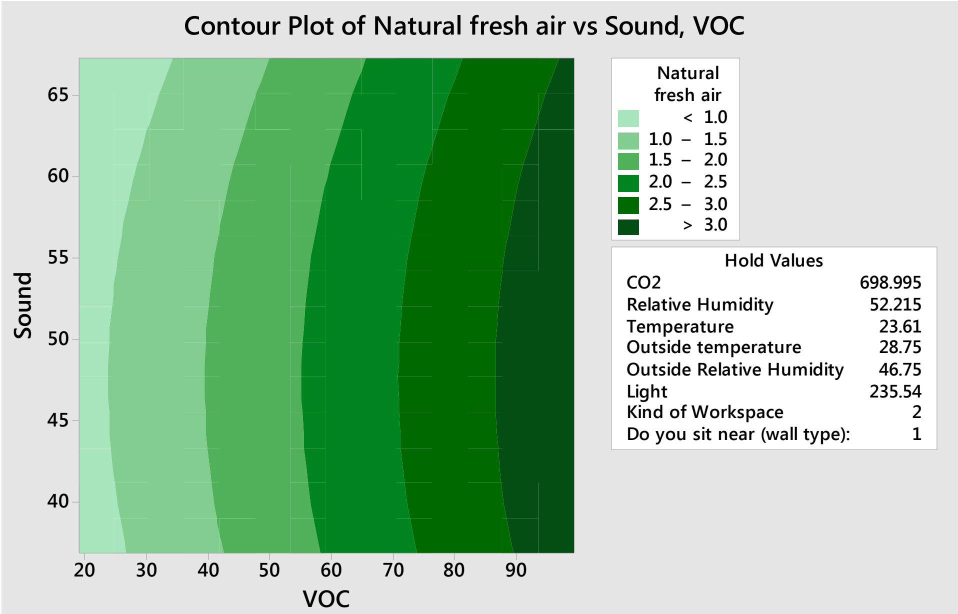


Figure 4.41- Contour Plot - Effect of Sound, VOC on Air Comfort (Natural Air)

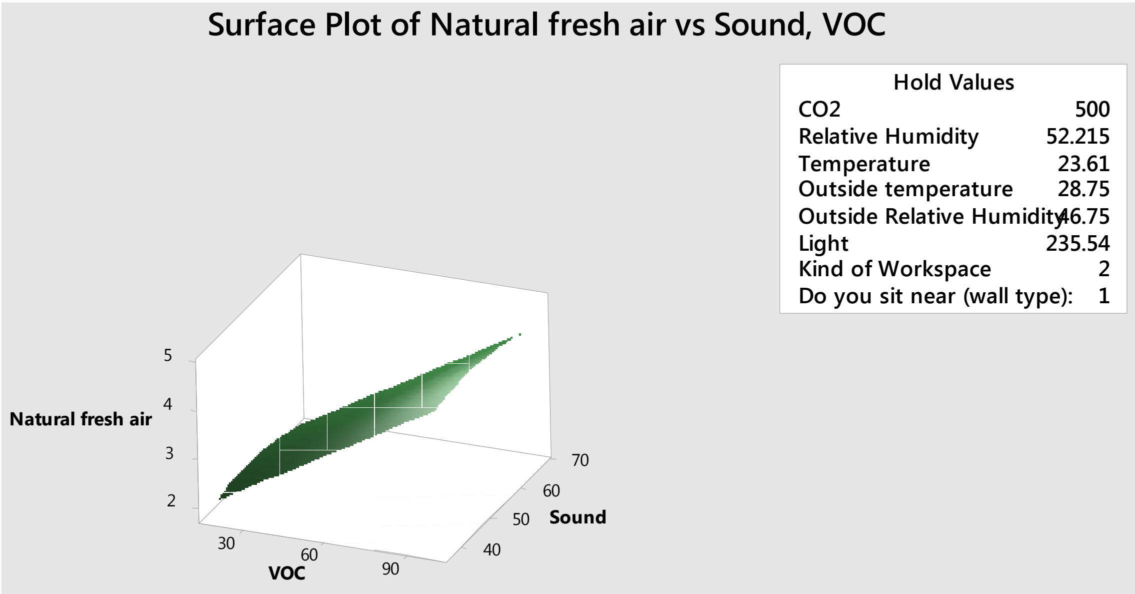


Figure 4.42 - Surface Plot - Effect of Sound, VOC on Air Comfort (Natural Air)

4.3.6.3 Effect of Outside Relative Humidity, VOC on Indoor Air Comfort (Natural Air) and its impact on Occupant Productivity

The impact of outside relative humidity and VOC on indoor air comfort and its effect on occupant productivity has been shown here (Figure 4.43, Figure 4.44). The plots are measured at the ideal hold values of various independent variables. Between outside relative humidity and VOC, only VOC levels have a significant effect on indoor air comfort (natural air) and its impact on productivity.

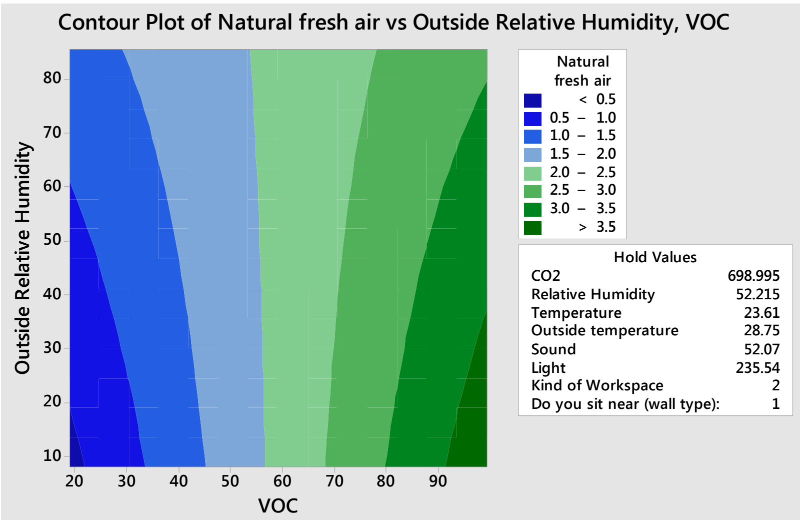


Figure 4.43 - Contour Plot - Effect of Outside RH, VOC on Air Comfort (Natural Air)

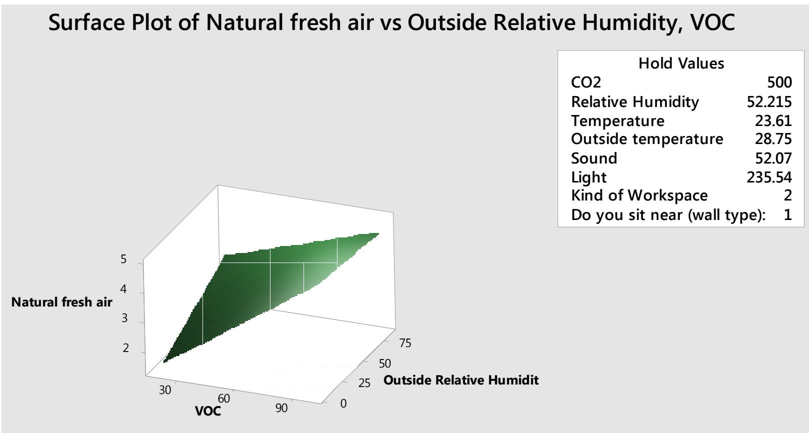


Figure 4.44 - Surface Plot - Effect of Outside RH, VOC on Air Comfort (Natural Air)

4.3.6.4 Effect of Relative Humidity, VOC on Indoor Air Comfort (Natural Air) and its impact on Occupant Productivity

The surface and contour plots below represent the effect of relative humidity and VOC on occupant's indoor air comfort (natural air) and its impact on productivity (Figure 4.45, Figure 4.46). Graphs indicate that both relative humidity and VOC have an impact on indoor air comfort and productivity. Graphs outline that 60% and above VOC free air have a positive impact , and the relative humidity's effect is dependent on VOC. For instance, at 70% VOC free air, up to 35% humidity and when VOC free air is 80%, the relative humidity's effect is positive up to 45% relative humidity.

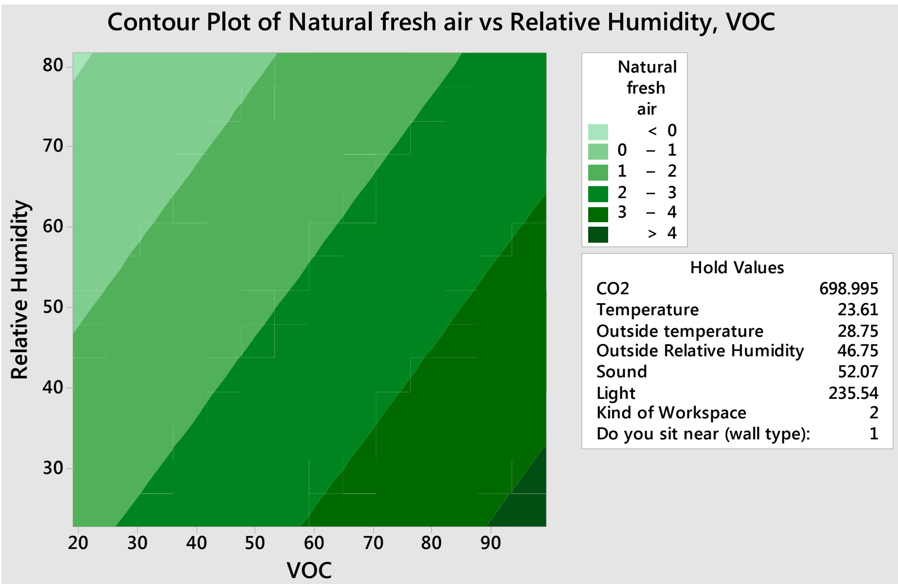


Figure 4.45 Contour Plot - Effect of Relative Humidity, VOC on Air Comfort (Natural Air)

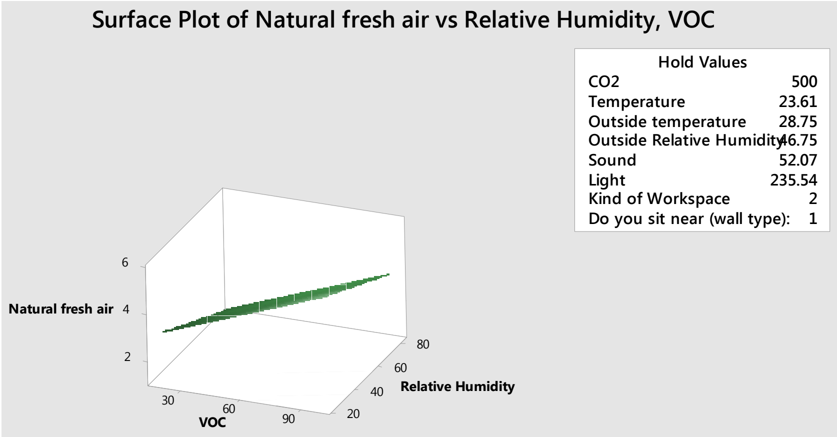


Figure 4.46 - Surface Plot - Effect of Relative Humidity, VOC on Air Comfort (Natural Air)

4.3.6.5 Effect of Carbon Dioxide and Light on Indoor Air Comfort (Natural Air) and its impact on Occupant Productivity

The charts below show the effect of carbon dioxide and light on indoor air comfort and its impact on occupant productivity (Figure 4.47, Figure 4.48). They highlight that carbon dioxide has a significant effect on indoor air comfort and also on productivity. Carbon dioxide has a positive effect on indoor air comfort (natural air) up to 450 ppm. It also outlines that natural or artificial light has no significant impact on indoor air comfort (natural air).

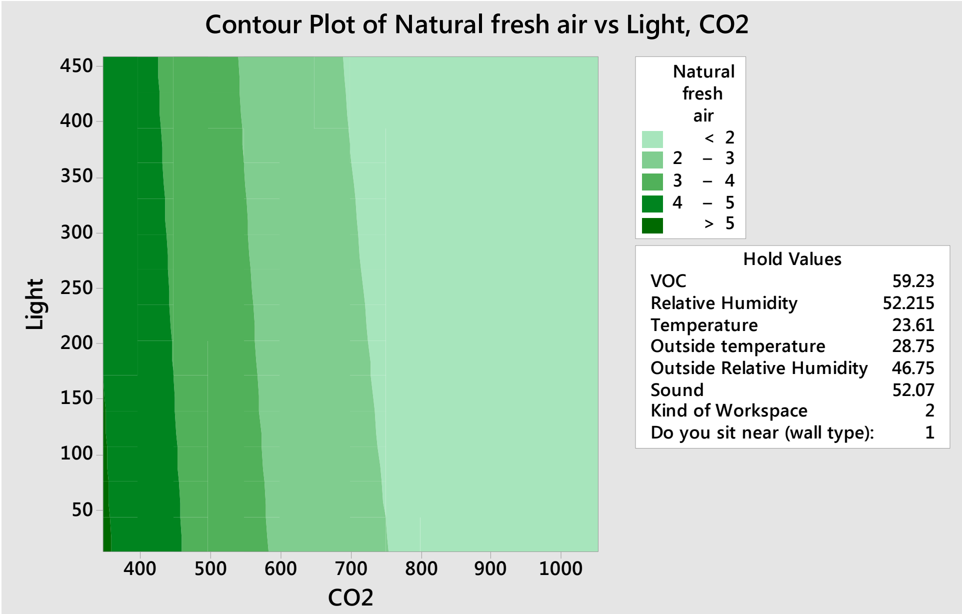


Figure 4.47 - Contour Plot - Effect of Carbon Dioxide and Light on Indoor Air Comfort (Natural Air)

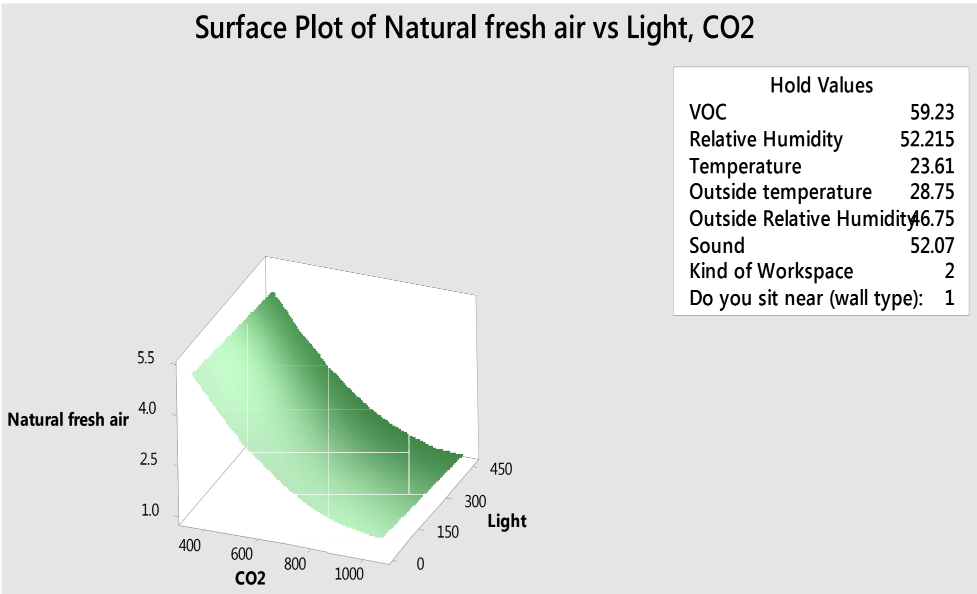


Figure 4.48 - Surface Plot - Effect of Carbon Dioxide and Light on Indoor Air Comfort (Natural Air)

4.3.6.6 Effect of Carbon Dioxide and Sound on Indoor Air Comfort (Natural Air) and its impact on Occupant Productivity

The contour and surface plots on the charts below present the effect of carbon dioxide and sound on indoor air comfort (natural air) and its impact on occupant productivity (Figure 4.49, Figure 4.50). The plotted lines describe that carbon dioxide has an inverse relationship with indoor air quality. The contour plot indicates that up to 450 ppm, carbon dioxide has a positive effect on the occupant's air comfort and also on productivity. The plots also show that sound does not have a significant impact on indoor air comfort and productivity.

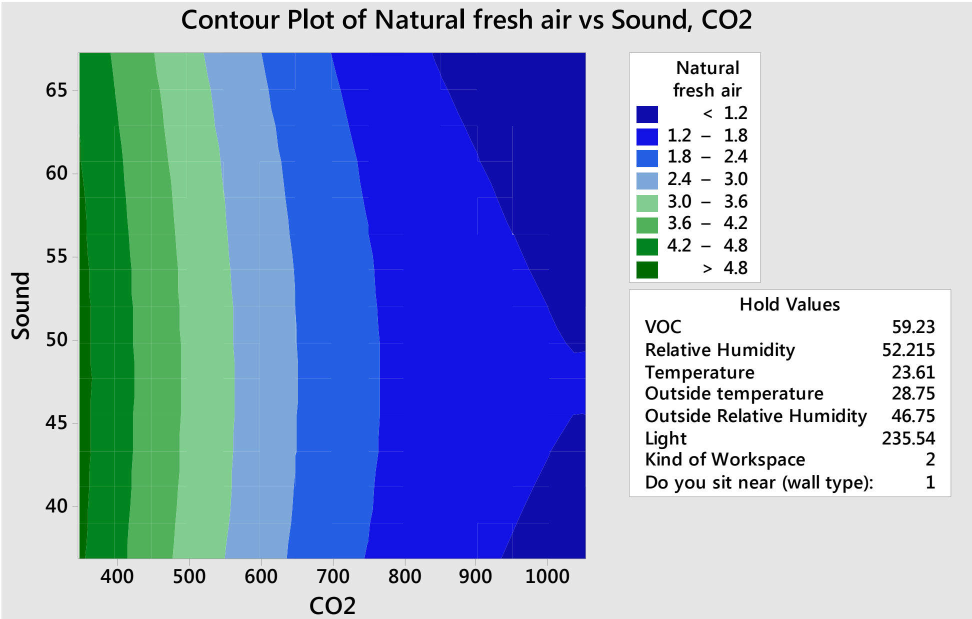


Figure 4.49 - Contour Plot - Effect of Carbon Dioxide and Sound on Indoor Air Comfort (Natural Air)

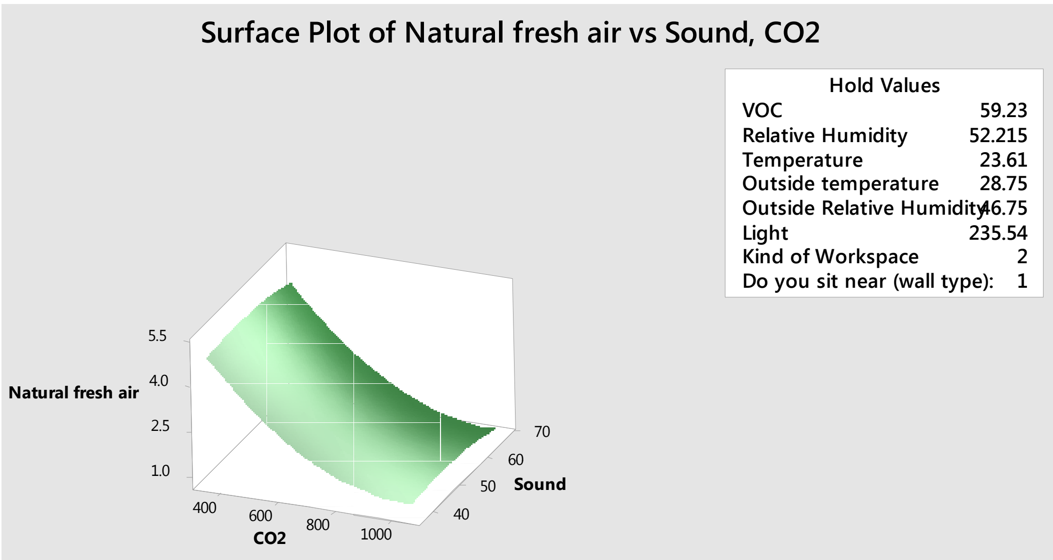


Figure 4.50 - Surface Plot - Effect of Carbon Dioxide and Sound on Indoor Air Comfort (Natural Air)

4.3.6.7 Effect of Carbon Dioxide and Outside Relative Humidity on Indoor Air Comfort (Natural Air) and its impact on Occupant Productivity

The surface and contour plots below present the effect of carbon dioxide and outdoor relative humidity on indoor air comfort and its impact on occupant productivity (Figure 4.51, Figure 4.52). They show that carbon dioxide is inversely related to indoor air comfort (natural air) and its impact on productivity. The contour plot shows that carbon dioxide has a positive effect on indoor air comfort up to 400ppm and neutral effect up to 530 ppm level. The outside relative humidity does not have a significant effect on air comfort and productivity.

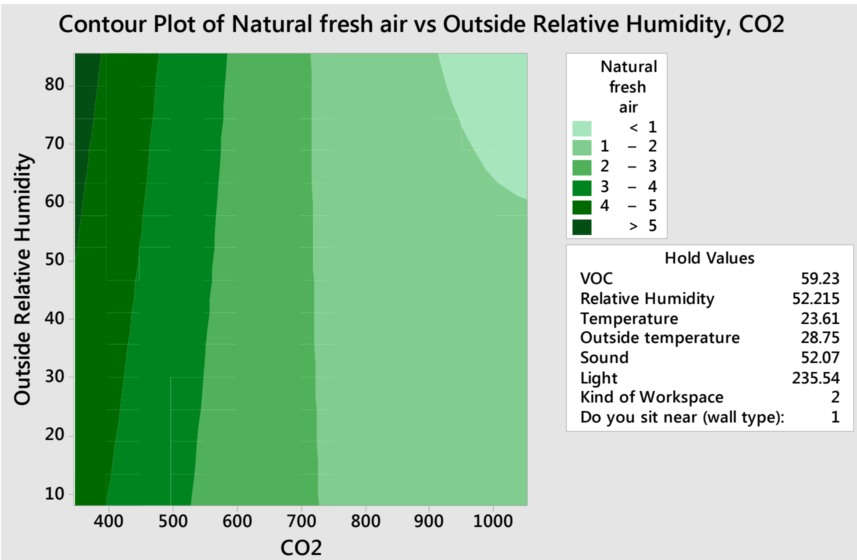


Figure 4.51- Contour Plot- Effect of Carbon Dioxide and Outside RH on Air Comfort (Natural Air)

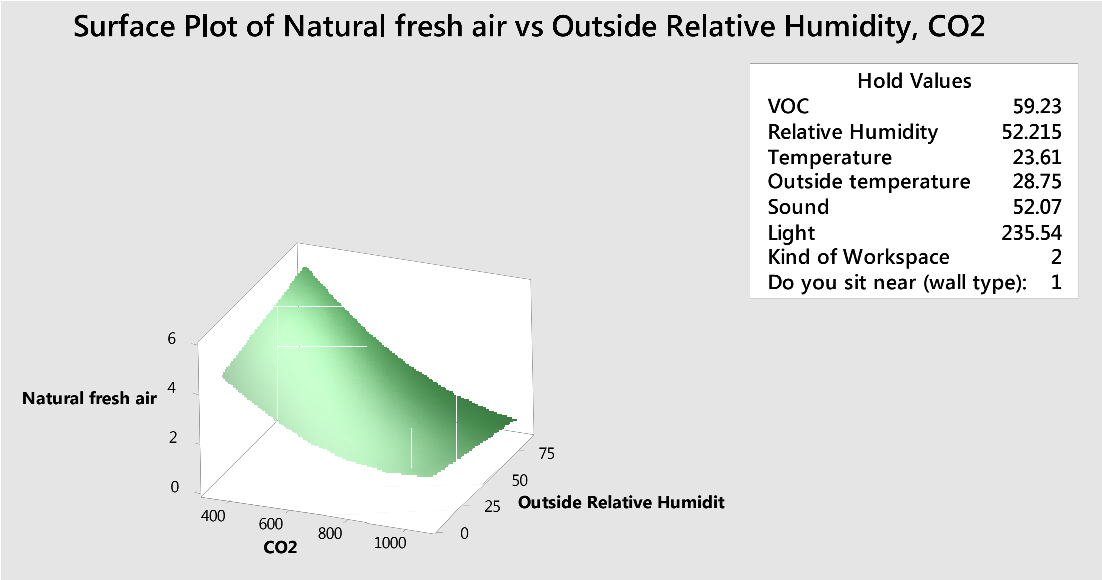


Figure 4.52 - Surface Plot - Effect of Carbon Dioxide and Outside RH on Air Comfort (Natural Air)

4.3.6.8 Effect of Carbon Dioxide and Outside Temperature on Indoor Air Comfort (Natural Air) and its impact on Occupant Productivity

These plots describe the effect of carbon dioxide and outside temperature on indoor air comfort and their impact on occupant productivity (Figure 4.53, Figure 4.54). Graphs outline that carbon dioxide has a positive effect up to 450 ppm and a neutral effect up to 625 ppm. The outside temperature has no significant effect on indoor air comfort.

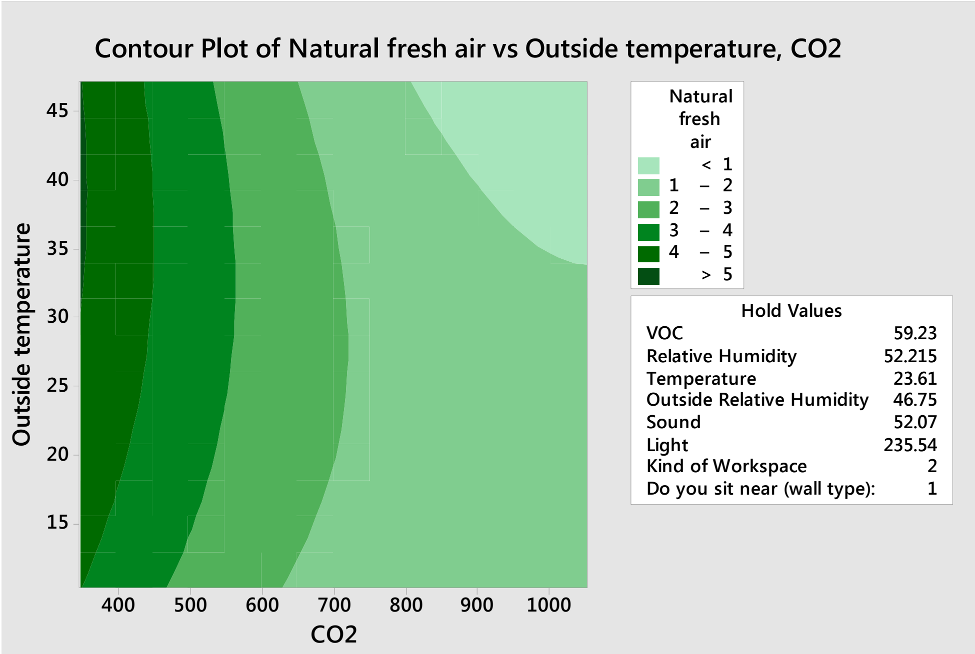


Figure 4.53 - Contour Plot - Effect of Carbon Dioxide and Outside Temperature on Air Comfort (Natural Air)

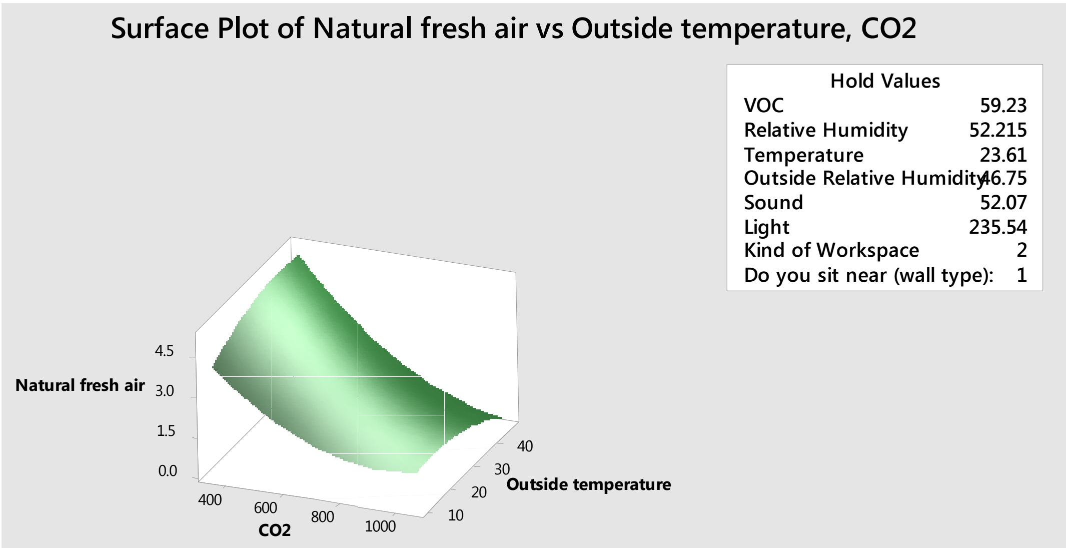


Figure 4.54 - Surface Plot - Effect of Carbon Dioxide and Outside Temperature on Air Comfort (Natural Air)

4.3.6.9 Effect of Carbon Dioxide and Temperature on Indoor Air Comfort (Natural Air) and its impact on Occupant Productivity

These charts represent the effect of carbon dioxide and temperature on indoor air comfort and its impact on productivity (Figure 4.55, Figure 4.56). They outline that carbon dioxide has a significant effect as compared to temperature. Carbon dioxide has a positive effect on indoor air comfort up to 525 ppm, neutral effect up to 675 ppm and adverse effect above it. It also indicates that temperature has no significant effect on the occupant's air comfort.

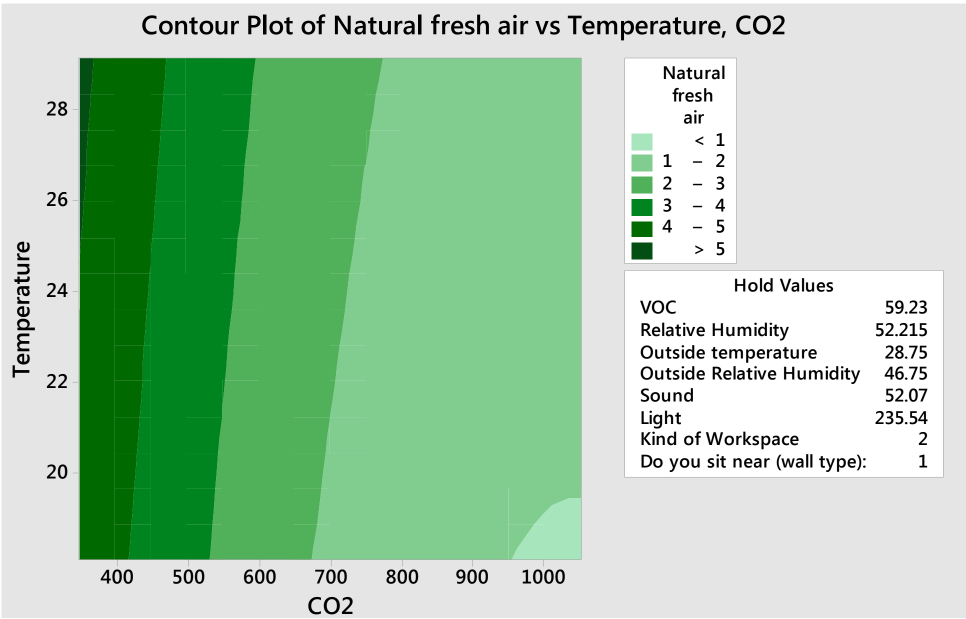


Figure 4.55 - Contour Plot - Effect of Carbon Dioxide and Temperature on Air Comfort (Natural Air)

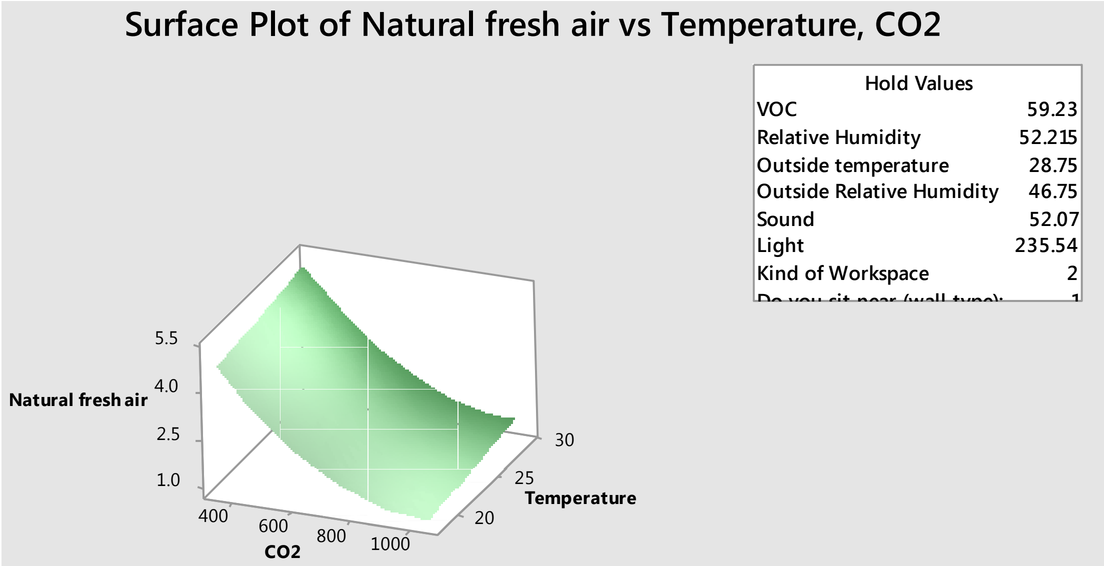


Figure 4.56 - Surface Plot - Effect of Carbon Dioxide and Temperature on Air Comfort (Natural Air)

4.3.6.10 Effect of Carbon Dioxide and Relative Humidity on Indoor Air Comfort (Natural Air) and its impact on Occupant Productivity

The charts below outline the effect of carbon dioxide and relative humidity on indoor air comfort and its impact on occupant productivity (Figure 4.57, Figure 4.58). Plots indicate that carbon dioxide has a more prominent effect on indoor air comfort than relative humidity. Contour plot highlights that carbon dioxide has a positive effect up to 550 ppm, neutral effect up to 700 ppm and negative effect above it. Relative Humidity has the least effect on indoor air comfort. The plots indicate that lower relative humidity has a positive impact on indoor air comfort and its impact on productivity.

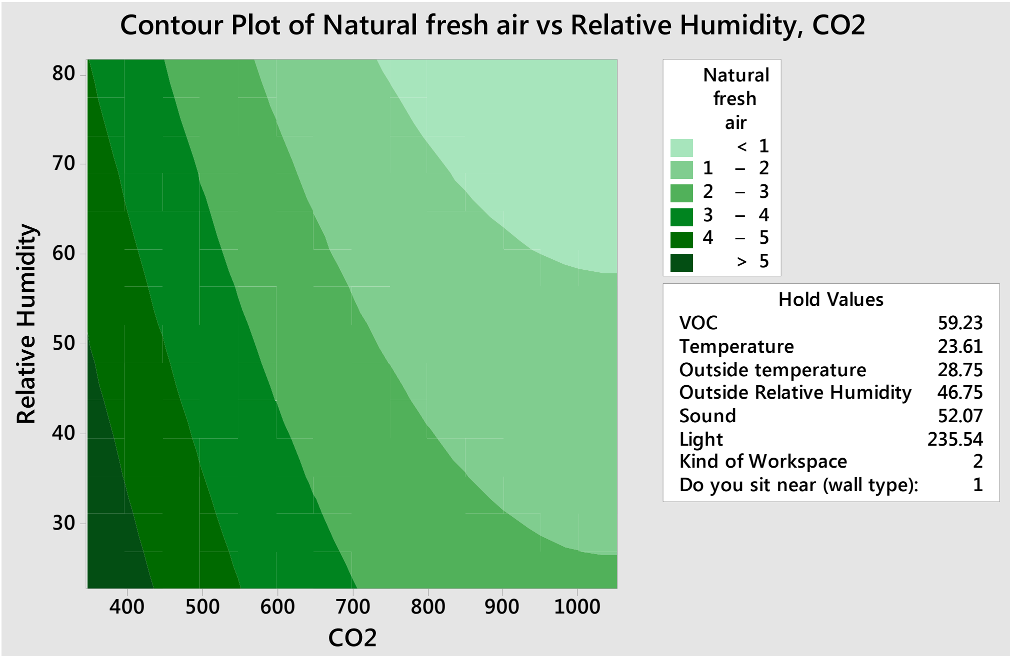


Figure 4.57 Contour Plot - Effect of Carbon Dioxide and Relative Humidity on Air Comfort (Natural Air)

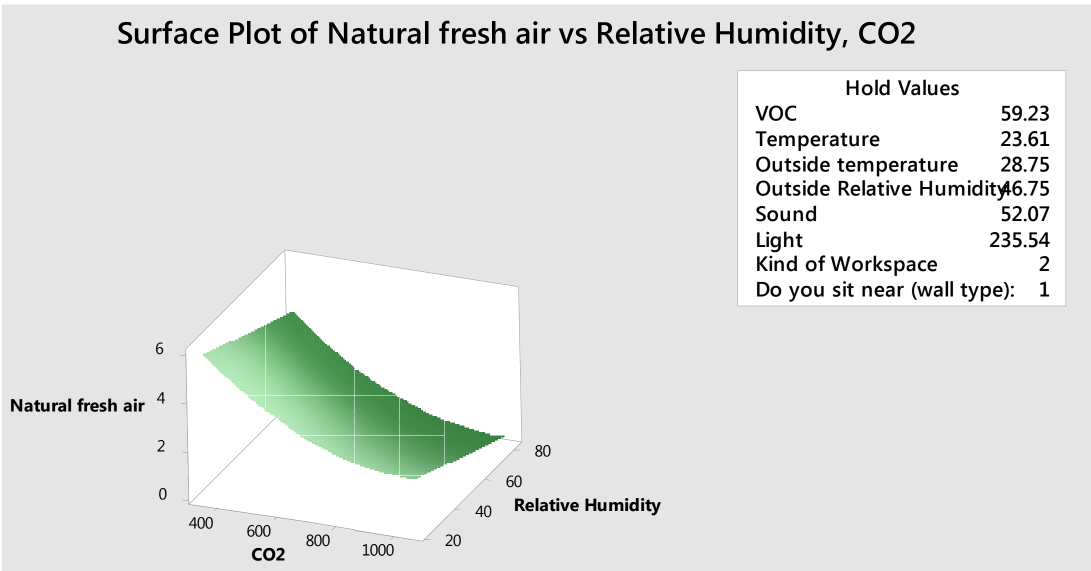


Figure 4.58 Surface Plot - Effect of Carbon Dioxide and Relative Humidity on Air Comfort (Natural Air)

4.3.6.11 Effect of Carbon Dioxide and VOC on Indoor Air Comfort (Natural Air) and its impact on Occupant Productivity

The visuals highlight the interaction between carbon dioxide and VOC and their effect on indoor air quality and its impact on occupant productivity (Figure 4.59, Figure 4.60). They suggest that VOC and carbon dioxide in indoor air inversely proportional to occupant's thermal comfort and productivity. Peak air comfort and productivity are achievable when carbon dioxide is below 500 ppm, and the air is above 80% VOC free. Both carbon dioxide and VOC have a significant effect on occupant's air comfort (natural air) and its impact on productivity.

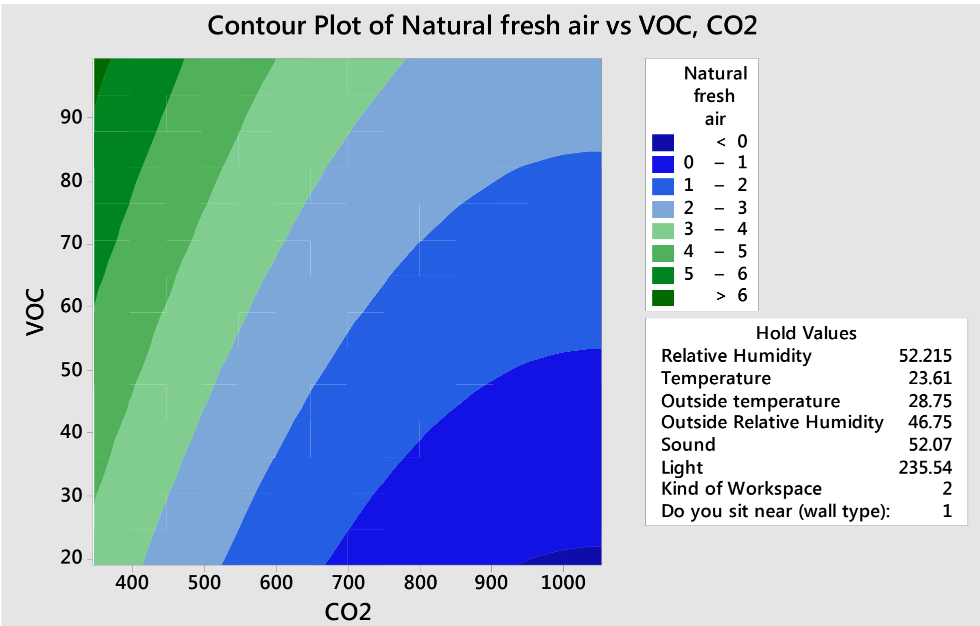


Figure 4.59 Contour Plot - Effect of Carbon Dioxide and VOC on Air Comfort (Natural Air)

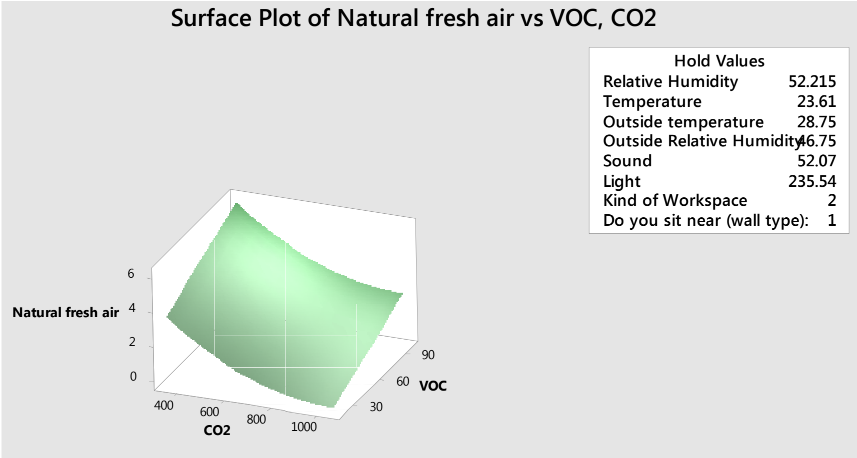


Figure 4.60 - Surface Plot - Effect of Carbon Dioxide and VOC on Air Comfort (Natural Air)

4.3.7 Summary

This question was aimed to identify the influence of various physical environment parameters on occupant's air comfort (natural air) and their impact on productivity. Primary results of the analysis:

1. Carbon dioxide, VOC have maximum impact on occupant's air comfort (natural air).
2. Derived regression equation can be used to determine the occupant's indoor air comfort of an occupant in a similar geographical and climatic context.
3. Optimum level (positive, very positive) of air comfort for natural air and productivity are observed below 500 ppm level of carbon dioxide and below and VOC from 75% (VOC free air) and above.
4. Relative humidity has a slight impact on indoor air comfort. It is observed that higher humidity leads to lower air comfort and occupant's perception of natural air.

4.4 Response Surface Regression for Indoor Air Comfort (Mechanical Ventilation) and Productivity

A response surface analysis of mechanical ventilation was done to identify the input variables that influence occupant's perception of natural air and how it affects their productivity. It produced the following:

- P-values for the independent factors their square and 2-way interactions
- R square (Coefficient of Determination)
- Residual Plots
- Regression Equation
- Pareto Chart
- Contour Plots
- Surface Plots

4.4.1 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	41	295.75	7.2135	30.64	0.000
Linear	15	81.870	5.4580	23.19	0.000
CO2	1	55.197	55.1971	234.48	0.000
VOC	1	0.024	0.0238	0.10	0.751
Relative Humidity	1	0.369	0.3688	1.57	0.212
Temperature	1	0.106	0.1062	0.45	0.502
Outside temperature	1	2.347	2.3474	9.97	0.002
Outside Relative Humidity	1	0.300	0.3004	1.28	0.259
Sound	1	0.012	0.0122	0.05	0.820
Light	1	0.426	0.4261	1.81	0.179
Kind of Workspace	4	0.997	0.2492	1.06	0.377
Do you sit near (wall type):	3	2.990	0.9966	4.23	0.006
Square	2	6.063	3.0315	12.88	0.000

CO2*CO2	1	3.660	3.6597	15.55	0.000
Sound*Sound	1	2.969	2.9688	12.61	0.000
2-Way Interaction	24	17.260	0.7192	3.06	0.000
CO2*VOC	1	1.022	1.0221	4.34	0.038
CO2*Light	1	1.564	1.5643	6.65	0.010
VOC*Light	1	1.516	1.5163	6.44	0.012
VOC*Kind of Workspace	4	2.617	0.6541	2.78	0.027
Relative Humidity*Light	1	1.018	1.0183	4.33	0.038
Temperature*Sound	1	2.502	2.5022	10.63	0.001
Outside temperature*Sound	1	1.121	1.1208	4.76	0.030
Outside temperature*Do you sit near (wall type):	3	4.470	1.4899	6.33	0.000
Outside Relative Humidity*Sound	1	0.930	0.9305	3.95	0.048
Outside Relative Humidity*Do you sit near (wall type):	3	1.718	0.5728	2.43	0.065
Light*Kind of Workspace	4	3.388	0.8469	3.60	0.007
Light*Do you sit near (wall type):	3	6.437	2.1458	9.12	0.000
Error	323	76.037	0.2354		
Lack-of-Fit	319	75.537	0.2368	1.89	0.285
Pure Error	4	0.500	0.1250		
Total	364	371.792			

Table 4.3 - Analysis of Variance – Indoor Air Comfort (Mechanical Ventilation)

The experiment was based on the following hypothesis,

- H_0 = Variable has no effect on occupant's indoor air comfort (Mechanical Ventilation) and its impact on productivity.
- H_{alt} = Variable has an effect on occupant's indoor air comfort (Mechanical Ventilation) and its impact on productivity.

The ANOVA is done using α=0.1.

If p-value $\geq$ 0.1, it indicates strong evidence of null hypothesis.

If p-value $\leq$ 0.1, it indicates strong evidence against the null hypothesis, hence rejecting the null hypothesis.

Based on the ANOVA, the following factors have an effect on the occupant's air comfort (Mechanical Ventilation) and its impact on the productivity of occupants (Table 4.3):

1. CO^2
2. Outside temperature
3. Wall type
4. CO^2*CO^2
5. CO^2*Light
6. VOC*Light
7. VOC*Kind of Workspace
8. Temperature*Sound
9. Outside temperature*Sound
10. Outside temperature*Wall type

The above factors affect indoor air comfort both directly and indirectly. All of these factors have different magnitudes of influence. It would be outlined in Pareto charts.

4.4.2 <u>The Coefficient of Determination (Multiple Correlation Coefficient)</u>

The coefficient of determination (adjusted R-square) value is 76.95%. It indicates that about 77% of the data fits the regression and there is a significant relationship between dependent and independent variables.

4.4.3 Residual Plots

Residual plots are used to determine the fit of model data (Figure 4.61).

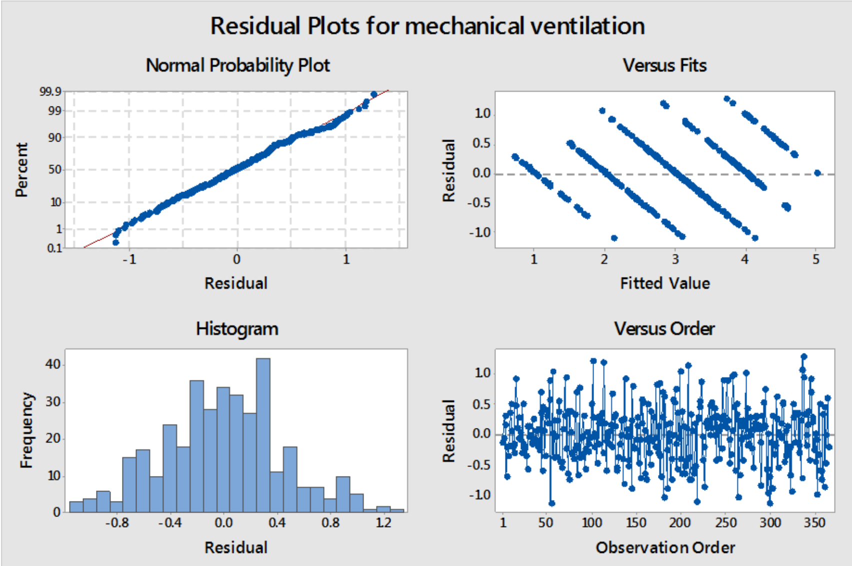


Figure 4.61- Residual Plots - Mechanical Ventilation

4.4.3.1 Normal Probability Plot

The residuals in the figure above follow the expected values (mainline). It shows the residuals are normally distributed.

4.4.3.2 Versus fits of fitted value plot

The scatter of the residuals varies as the fitted value increases. It indicates that residuals are unequal.

4.4.3.3 Residual Histogram

Histogram figure above has a bell curve with few outliers. It indicates that data is normally distributed.

4.4.3.4 Residual versus order plot

Residuals in the above figure are between -1 to 1, and no pattern is observed. It indicates the regression assumptions are satisfied.

4.4.4 Regression equation

Mechanical Ventilation = 1.27 - 0.00785 CO2 + 0.0319 VOC + 0.00913 Relative Humidity
- 0.370 Temperature + 0.1035 Outside temperature
+ 0.0353 Outside Relative Humidity + 0.1930 Sound + 0.01239 Light
- 0.863 Kind of Workspace_1 - 0.306 Kind of Workspace_2
+ 1.322 Kind of Workspace_3 + 0.47 Kind of Workspace_4
- 0.621 Kind of Workspace_5 + 1.658 Do you sit near (wall type):_1
+ 0.241 Do you sit near (wall type):_2
- 0.448 Do you sit near (wall type):_3
- 1.451 Do you sit near (wall type):_4 + 0.000005 CO2*CO2
- 0.002431 Sound*Sound - 0.000028 CO2*VOC - 0.000007 CO2*Light
- 0.000059 VOC*Light - 0.00622 VOC*Kind of Workspace_1
+ 0.00142 VOC*Kind of Workspace_2 - 0.01523 VOC*Kind of Workspace_3
+ 0.01692 VOC*Kind of Workspace_4
+ 0.0031 VOC*Kind of Workspace_5
- 0.000052 Relative Humidity*Light + 0.00731 Temperature*Sound
- 0.00262 Outside temperature*Sound
- 0.0872 Outside temperature*Do you sit near (wall type):_1
+ 0.0055 Outside temperature*Do you sit near (wall type):_2
+ 0.0324 Outside temperature*Do you sit near (wall type):_3
+ 0.0492 Outside temperature*Do you sit near (wall type):_4
- 0.000750 Outside Relative Humidity*Sound
- 0.01780 Outside Relative Humidity*Do you sit near (wall type):_1
+ 0.00213 Outside Relative Humidity*Do you sit near (wall type):_2
+ 0.00640 Outside Relative Humidity*Do you sit near (wall type):_3
+ 0.00927 Outside Relative Humidity*Do you sit near (wall type):_4
+ 0.00434 Light*Kind of Workspace_1
+ 0.000673 Light*Kind of Workspace_2
- 0.00167 Light*Kind of Workspace_3
- 0.00469 Light*Kind of Workspace_4
+ 0.00134 Light*Kind of Workspace_5
+ 0.00759 Light*Do you sit near (wall type):_1
- 0.001385 Light*Do you sit near (wall type):_2
- 0.003425 Light*Do you sit near (wall type):_3
- 0.002782 Light*Do you sit near (wall type):_4

4.4.4.1 Equation explanation

The regression equation shows various variables that have an effect on occupant's indoor air comfort (mechanical ventilation) and its impact on productivity. It shows that carbon dioxide, temperature, sound, wall type has an influence on occupant's indoor comfort levels (mechanical ventilation) and its impact on productivity. Along with the factors mentioned above, few more linear, square and interactions contribute to the final output.

As part of the analysis, various types of graphs have been used to show the impact of different input variable on the output variable.

4.4.5 Pareto chart

Pareto chart is used to present the independent variable's magnitude of effect on the output variable (Figure 4.62). The chart has set 1.65 of standardized effect as the reference line to identify variables that have an effect on occupant's indoor air comfort (mechanical ventilation) and its impact on productivity.

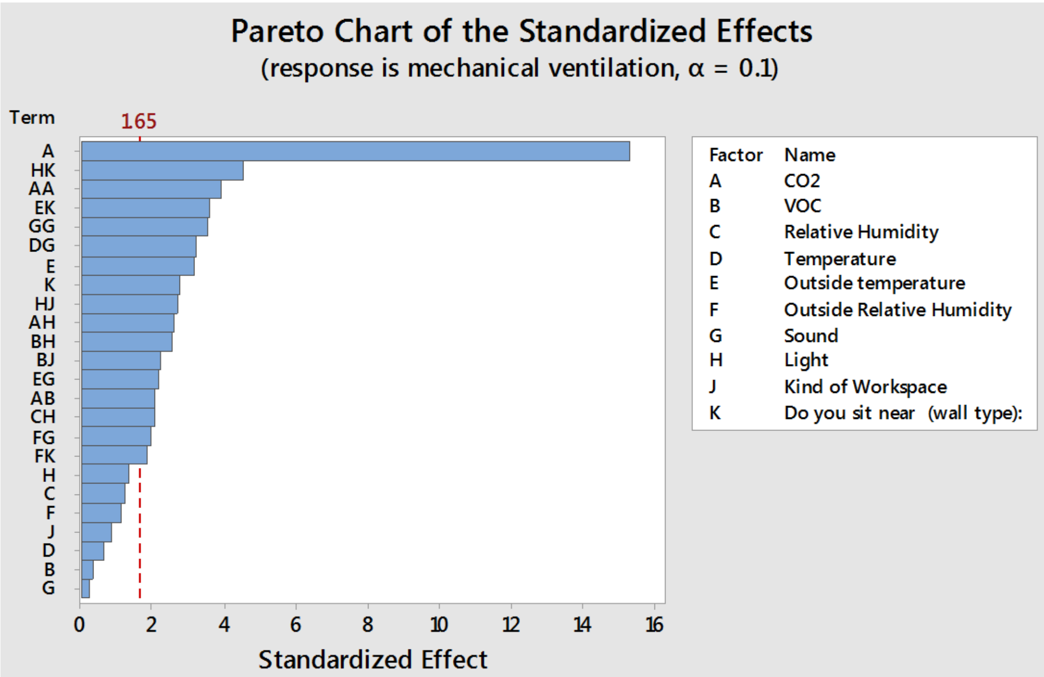


Figure 4.62 - Pareto Chart - Mechanical Ventilation

Following variables have a significant effect:

1. Carbon Dioxide (Maximum implications)
2. Light*Wall type
3. Carbon Dioxide*Carbon Dioxide
4. Outside Temperature*Outside Relative Humidity
5. Sound*Sound
6. Temperature*Sound
7. Outside Temperature
8. Wall type
9. Light*Kind of Workspace
10. Carbon Dioxide*VOC

4.4.6 Contour and Surface Plots

The plot lines have been used to identify optimal results by showing the effect of two independent variables on the dependent variable. The researcher has only discussed the scenarios that show important impacts or results on indoor air comfort (mechanical ventilation) and its impact on productivity.

4.4.6.1 Effect of Light, Sound on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

Contour and surface plots outline the following (Figure 4.63, Figure 4.64):

- Light has a direct impact on indoor air comfort and productivity. Optimum range is 250- 450 Lux level.
- It also indicates that between sound and light, the sound level does not have any impact on indoor air comfort.

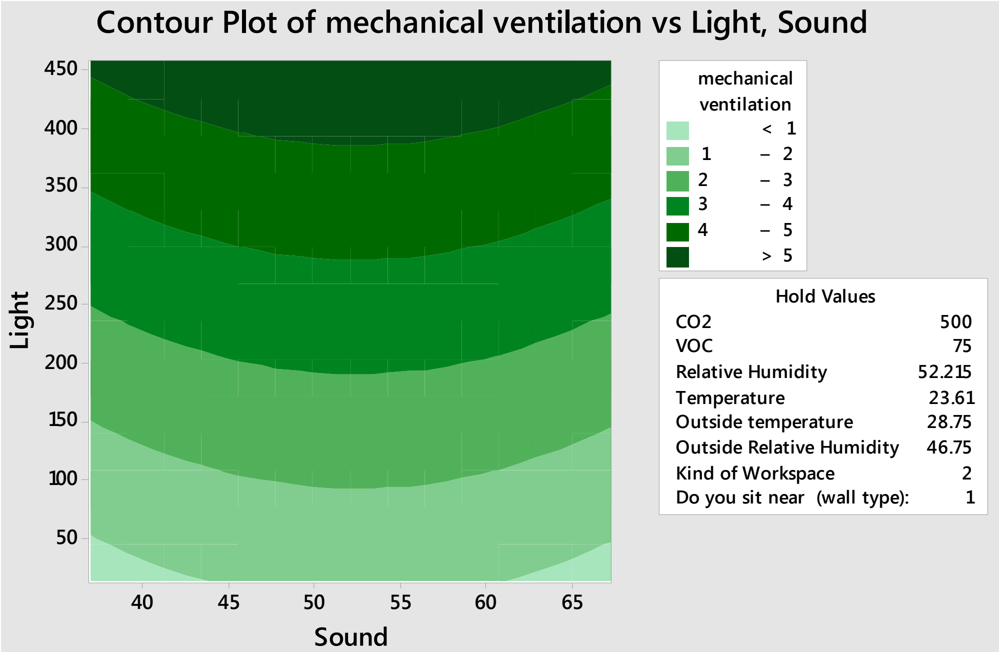


Figure 4.63 Contour Plot - Effect of Light, Sound on Air Comfort (Mechanical Ventilation)

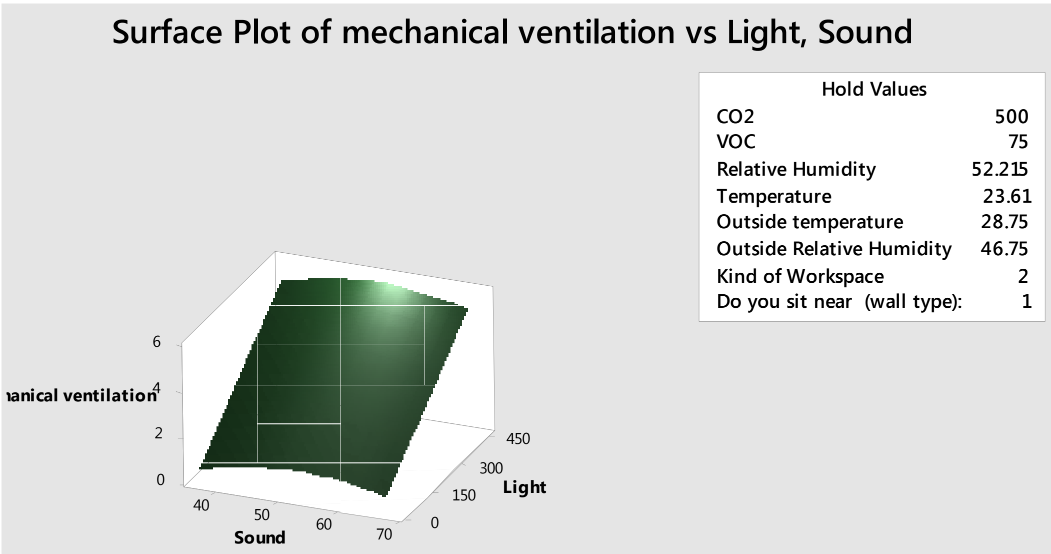


Figure 4.64 - Surface Plot - Effect of Light, Sound on Air Comfort (Mechanical Ventilation)

4.4.6.2 Effect of Light, Outside Relative Humidity on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

The charts below outline the following (Figure 4.65, Figure 4.66):

- Light has a significant effect on indoor air comfort levels for occupants (mechanical ventilation) and also on their productivity.
- Outside relative humidity has minimal impact.

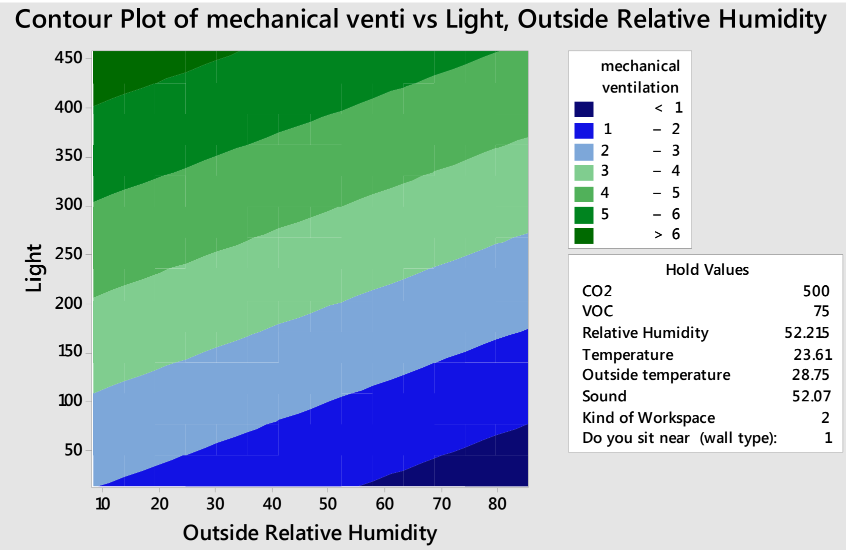


Figure 4.65 - Contour Plot - Effect of Light, Outside R.H. on Air Comfort (Mechanical Ventilation)

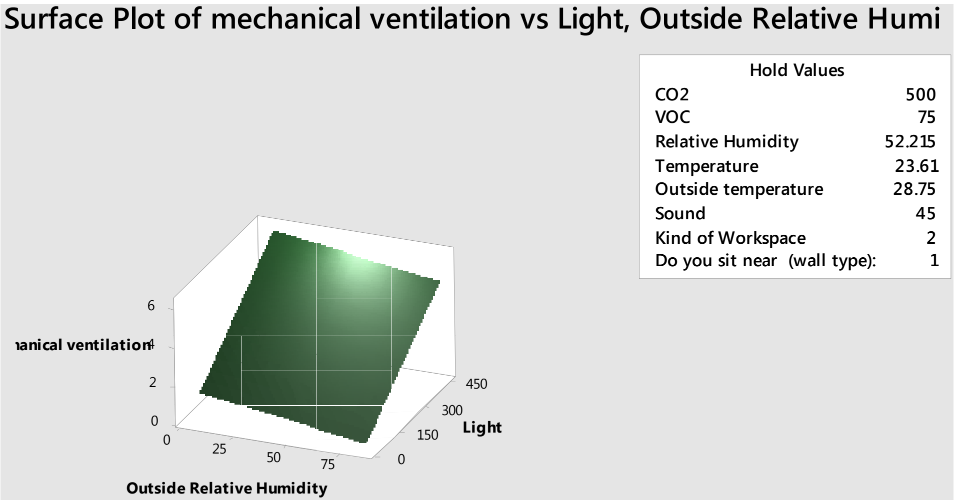


Figure 4.66 - Surface Plot - Effect of Light, Outside R.H. on Air Comfort (Mechanical Ventilation)

4.4.6.3 Effect of Light, Outside Temperature on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

The contour and surface plots below (Figure 4.67, Figure 4.68) highlight the following:

- Both light and outside temperatures have an impact on indoor air comfort (mechanical ventilation) and its impact on productivity.
- Higher Lux levels positively influence occupant indoor air comfort and productivity while higher outside temperature has an adverse effect on it.
- This outlines that outside temperature affects the quality of indoor air through mechanical ventilation.

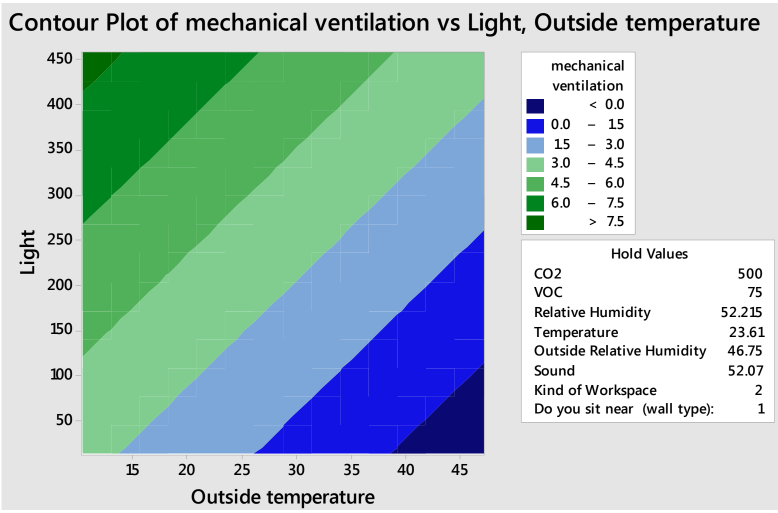


Figure 4.67 – Contour Plot - Effect of Light, Outside Temperature on Air Comfort (Mech. Ventilation)

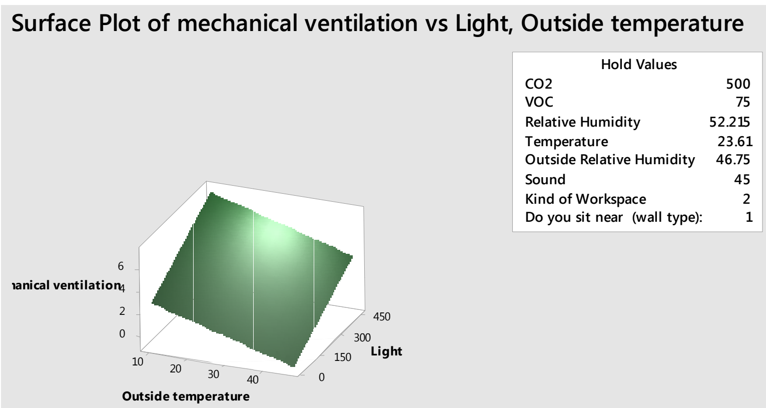


Figure 4.68 - Surface Plot - Effect of Light, Outside Temperature on Air Comfort (Mechanical Ventilation)

4.4.6.4 Effect of Sound, Outside Temperature on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

These plot lines (Figure 4.69, Figure 4.70) highlight the following:

- The outside temperature has a negative correlation with indoor air comfort and productivity.
- Sound does not have an impact on indoor air comfort and productivity.

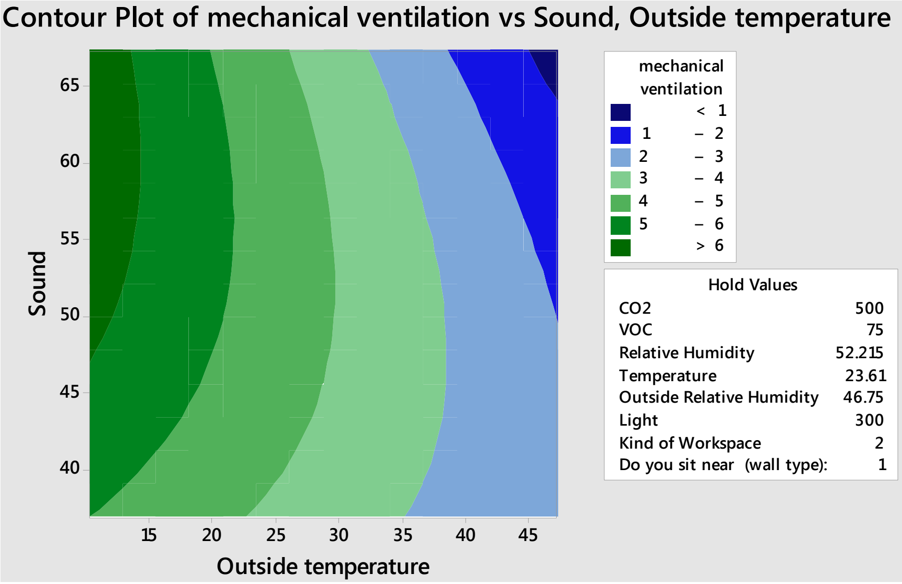


Figure 4.69 - Contour Plot - Effect of Sound, Outside Temperature on Air Comfort (Mech. Ventilation)

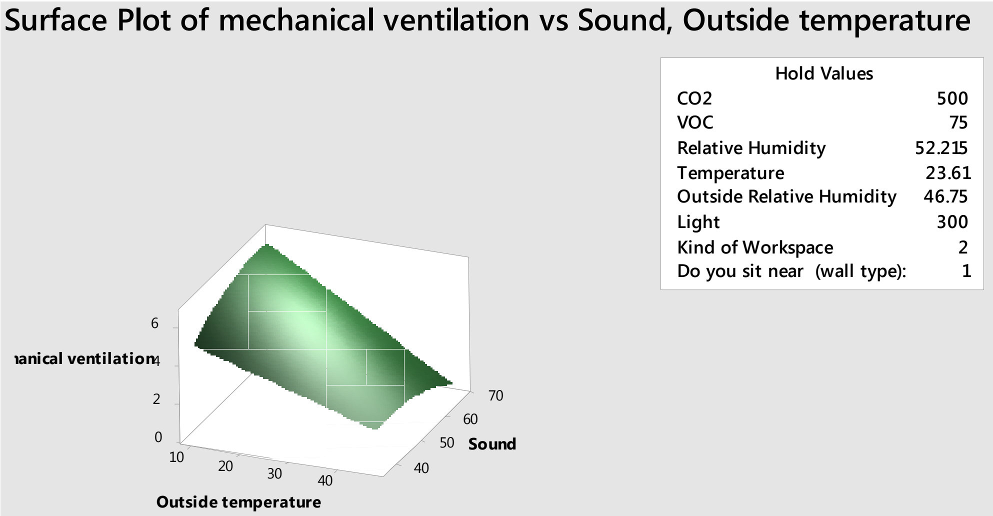


Figure 4.70 Surface Plot - Effect of Sound, Outside Temperature on Air Comfort (Mechanical Ventilation)

4.4.6.5 Effect of Outside Relative Humidity, Outside Temperature on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

These visuals outline the following (Figure 4.71, Figure 4.72):

- Both outside temperature and relative humidity have an adverse effect on occupant indoor air comfort and productivity.

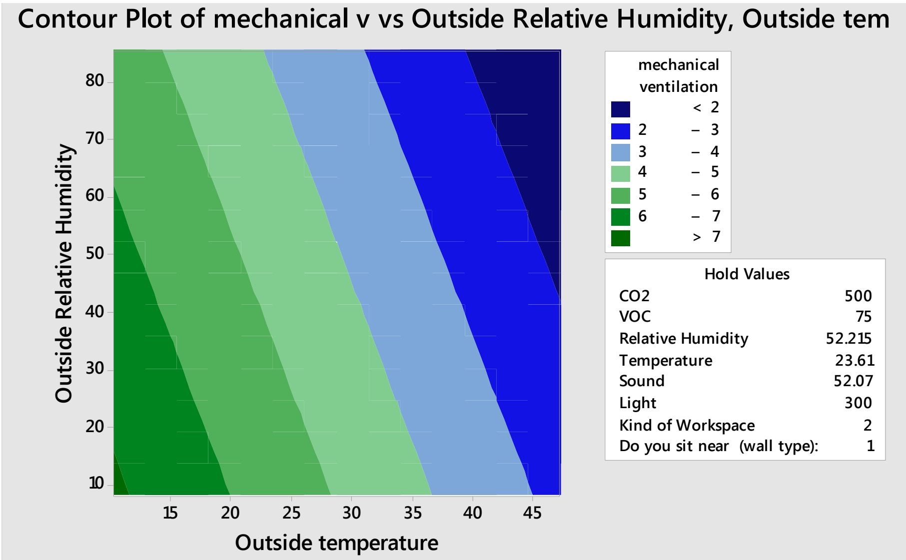


Figure 4.71Contour Plot - Effect of Outside R.H., Outside Temperature on Air Comfort (Mech. Ventilation)

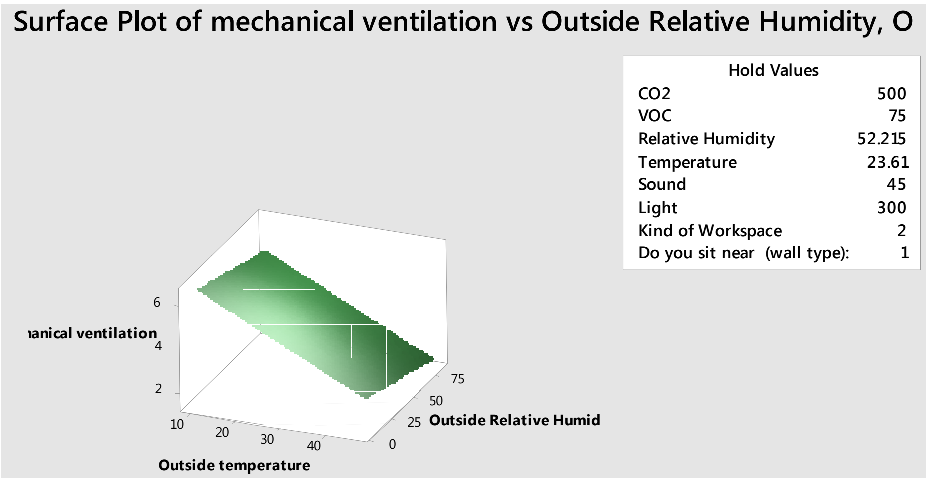


Figure 4.72 Surface Plot - Effect of Outside R.H., Outside Temperature on Air Comfort (Mech. Ventilation)

4.4.6.6 Effect of Relative Humidity, Sound on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

Below, the plot lines show the following (Figure 4.73 & Figure 4.74):

- Relative humidity has a negative correlation with indoor air comfort and its impact on productivity.
- Sound between 45-55 dB has a positive impact on productivity. Previously, results have indicated that sound does not have an impact on air comfort in the natural air system.

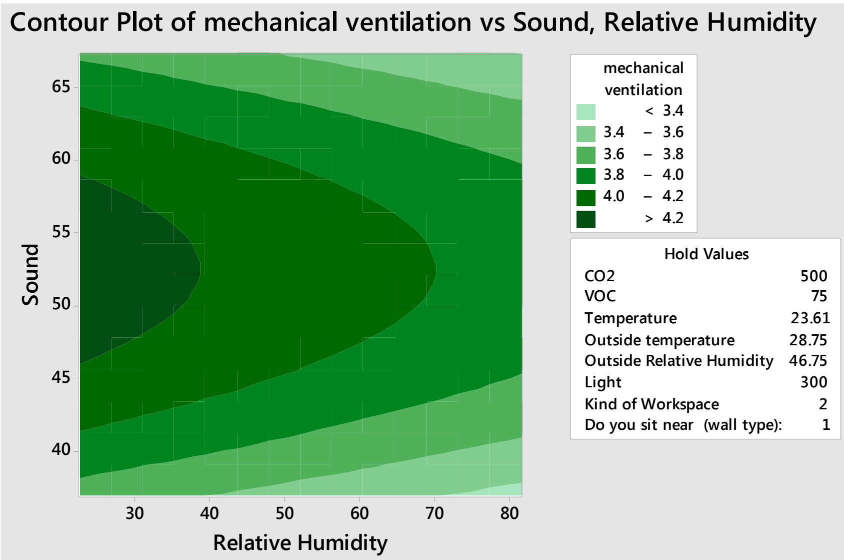


Figure 4.73 Contour Plot - Effect of Relative Humidity, Sound on Air Comfort (Mechanical Ventilation)

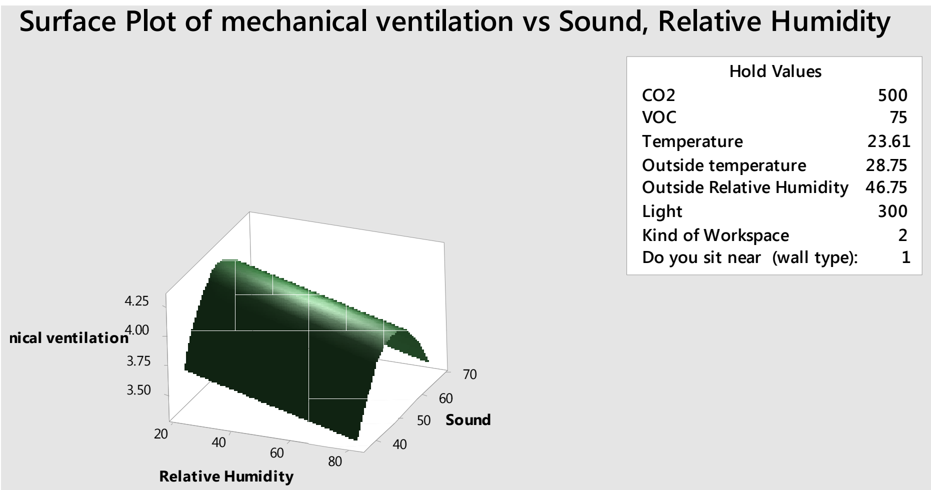


Figure 4.74 – Surface Plot - Effect of Relative Humidity, Sound on Air Comfort (Mechanical Ventilation)

4.4.6.7 Effect of Temperature, VOC on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

Below, the contour and surface plot lines show the following (Figure 4.75, Figure 4.76):

- Both VOC and temperature have an influence on indoor air comfort and its impact on productivity.
- Higher VOC free air leads to improve indoor air comfort and productivity.

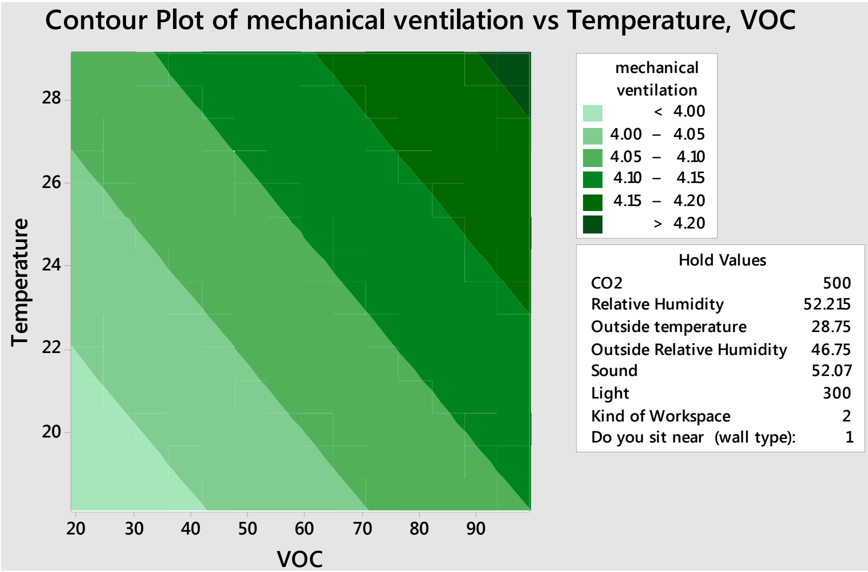


Figure 4.75 Contour Plot - Effect of Temperature, VOC on Air Comfort (Mechanical Ventilation)

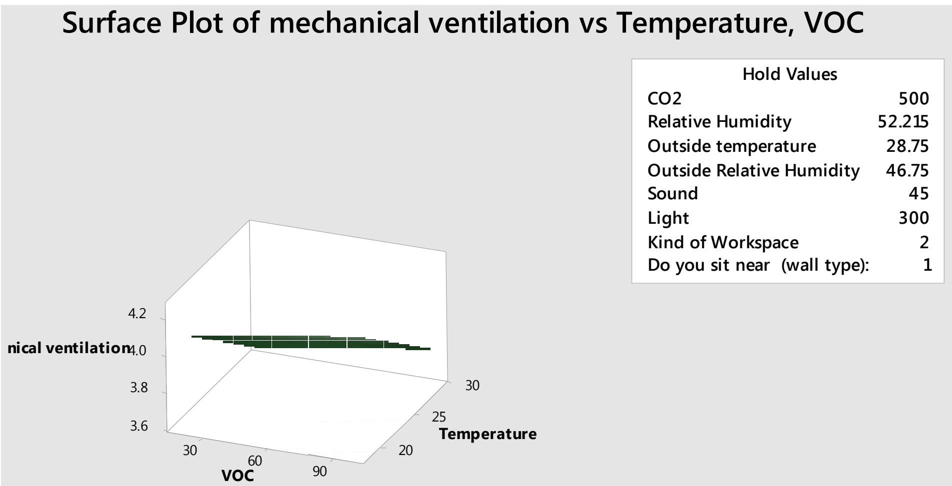


Figure 4.76 Surface Plot - Effect of Temperature, VOC on Air Comfort (Mechanical Ventilation)

4.4.6.8 Effect of Relative Humidity, VOC on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

The charts below highlight that (Figure 4.77, Figure 4.78):

- Both VOC and relative humidity have an influence on occupant's indoor air comfort and productivity.
- Higher VOC free air leads to an increase in air comfort and productivity.
- Higher relative humidity leads to lower indoor air comfort and productivity. Optimum relative humidity levels are observed to be below 60%

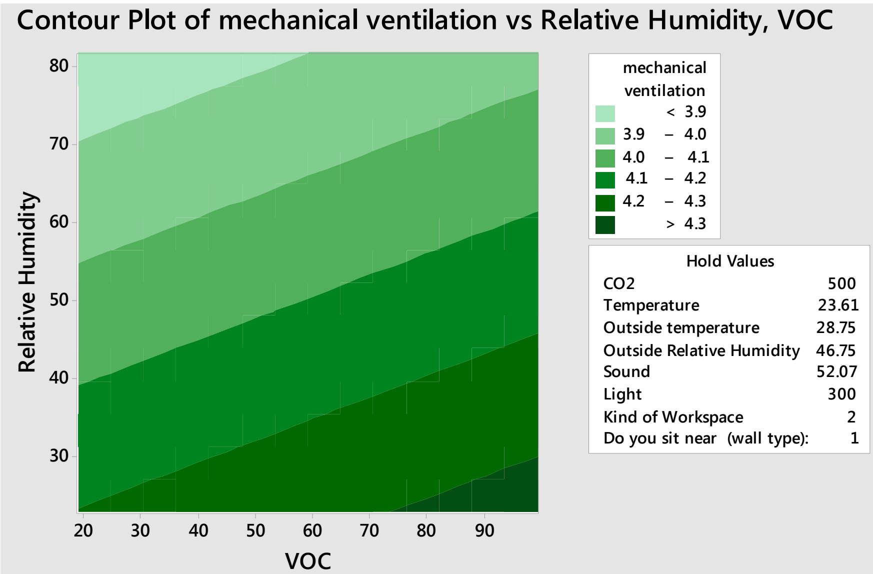


Figure 4.77 - Contour Plot - Effect of Relative Humidity, VOC on Air Comfort (Mechanical Ventilation)

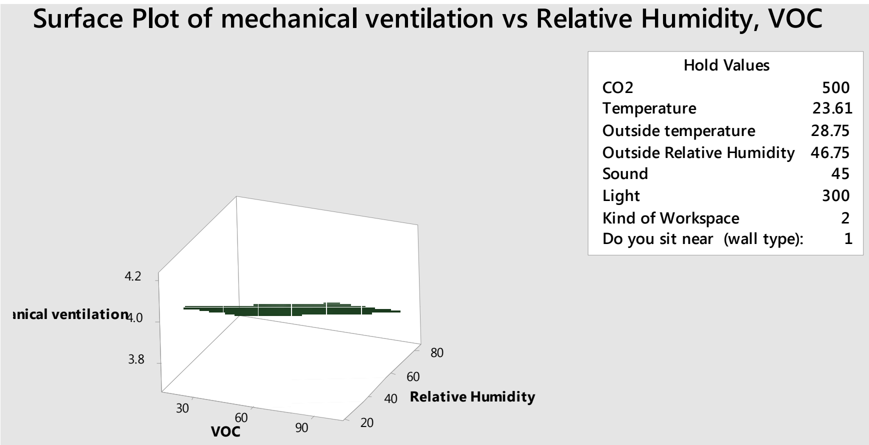


Figure 4.78 - Surface Plot - Effect of Relative Humidity, VOC on Air Comfort (Mechanical Ventilation)

4.4.6.9 Effect of Light, Carbon Dioxide on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

These charts outline that (Figure 4.79, Figure 4.80):

- Both light and carbon dioxide have an effect on indoor air comfort and productivity.
- Higher lux levels lead to higher comfort and productivity. Optimum lux level range is 250-450 lux.
- Higher carbon dioxide in air leads to lower productivity. Optimum carbon dioxide level is achieved below 450 ppm.

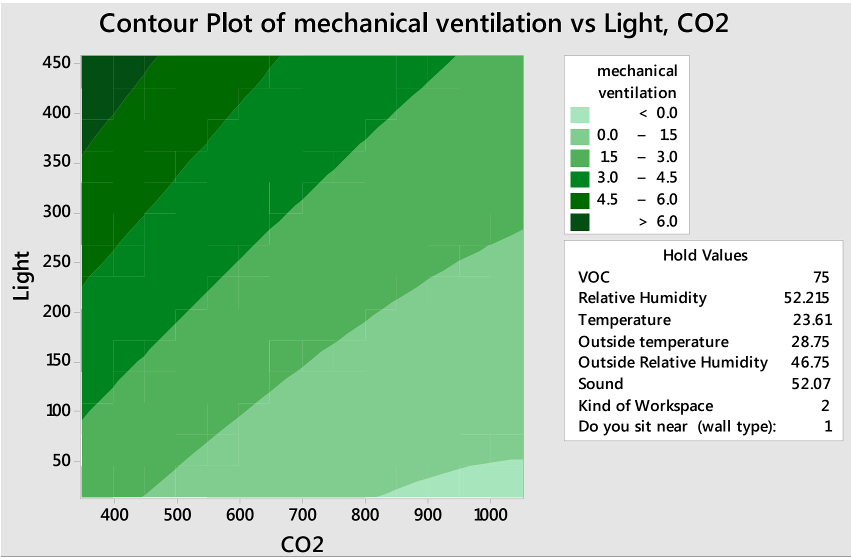


Figure 4.79 - Contour Plot - Effect of Light, Carbon Dioxide on Air Comfort (Mechanical Ventilation)

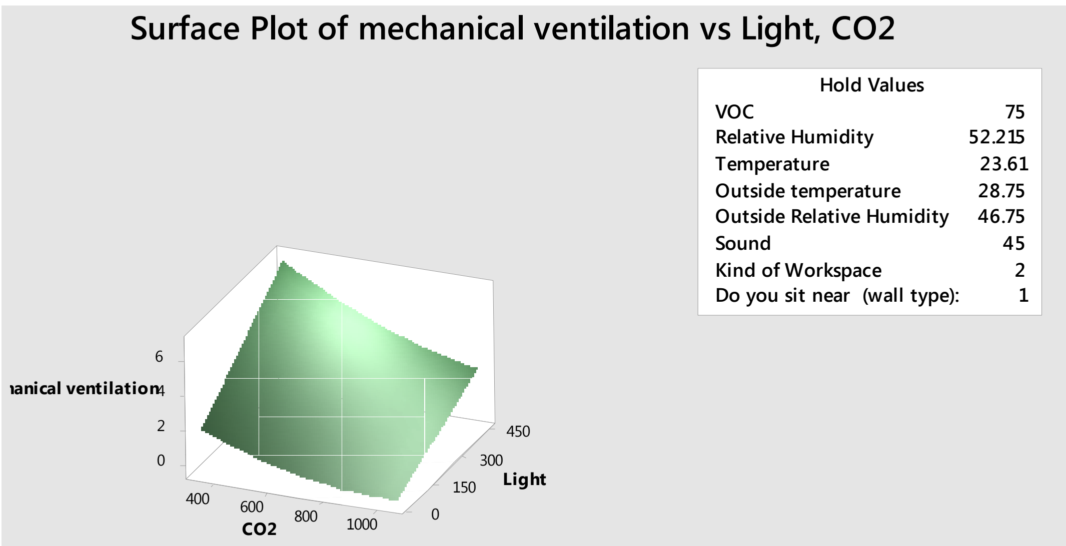


Figure 4.80 - Surface Plot - Effect of Light, Carbon Dioxide on Air Comfort (Mechanical Ventilation)

4.4.6.10 Effect of Sound, Carbon Dioxide on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

These plot lines (Figure 4.81, Figure 4.82) show the following:

- Between sound and carbon dioxide, the sound has minimal effect on indoor air comfort and productivity.
- Carbon dioxide has a significant effect on indoor air comfort and productivity. The optimum range of carbon dioxide range is 0 - 450 ppm.

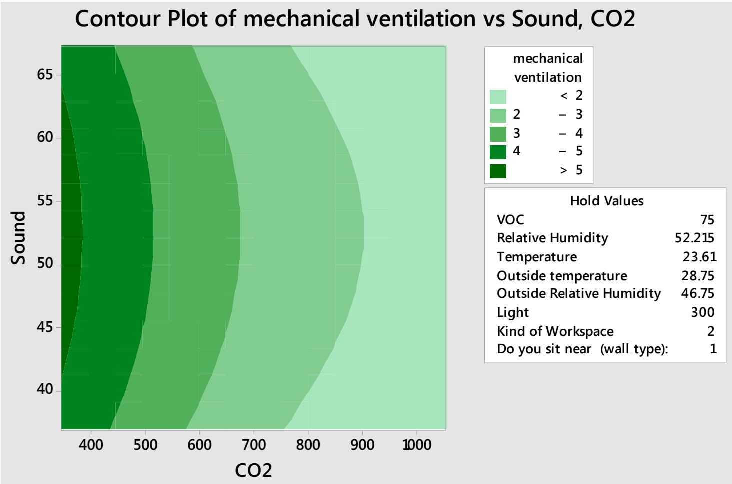


Figure 4.81Contour Plot - Effect of Sound, Carbon Dioxide on Air Comfort (Mechanical Ventilation)

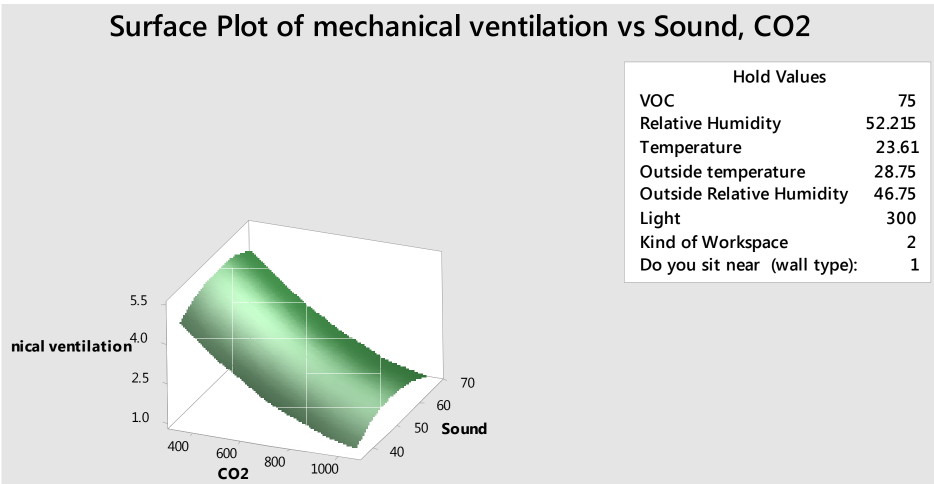


Figure 4.82 Surface Plot - Effect of Sound, Carbon Dioxide on Air Comfort (Mechanical Ventilation)

4.4.6.11 Effect of Outside Relative Humidity, Carbon Dioxide on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

The visuals show that: (Figure 4.83, Figure 4.84) that:

- Both outside relative humidity and carbon dioxide affect indoor air comfort and productivity.
- Higher outside relative humidity has a negative impact on air comfort and productivity. Optimum levels of outside relative humidity are below 60%.
- Higher carbon dioxide levels lead to lower air comfort and productivity. Optimum carbon dioxide level is observed to be below 600 ppm.

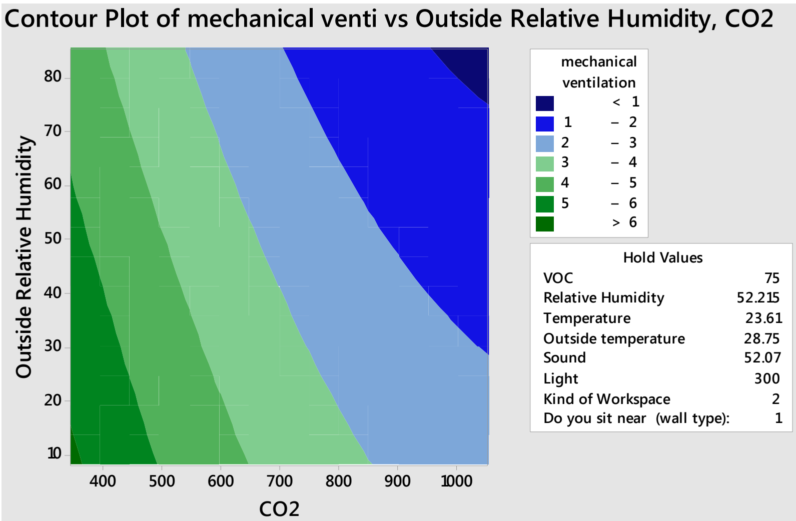


Figure 4.83 Contour Plot - Effect of Outside R.H, Carbon Dioxide on Air Comfort (Mechanical Ventilation)

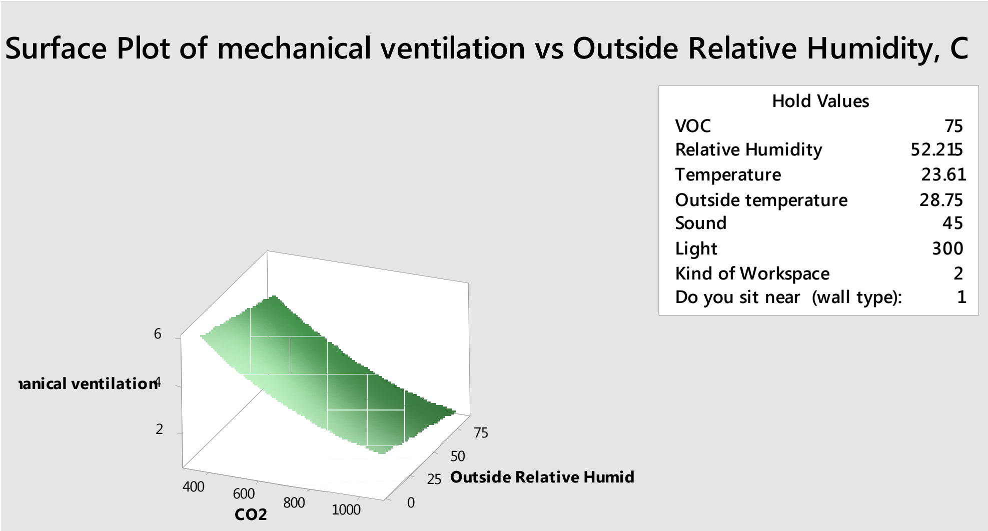


Figure 4.84 Surface Plot - Effect of Outside R.H, Carbon Dioxide on Air Comfort (Mech. Ventilation)

4.4.6.12 Effect of Outside Temperature, Carbon Dioxide on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

These charts show (Figure 4.85, Figure 4.86) that:

- Both outside temperature and carbon dioxide have a negative correlation with indoor air comfort and productivity.
- Optimum carbon dioxide levels are observed below 550 ppm.

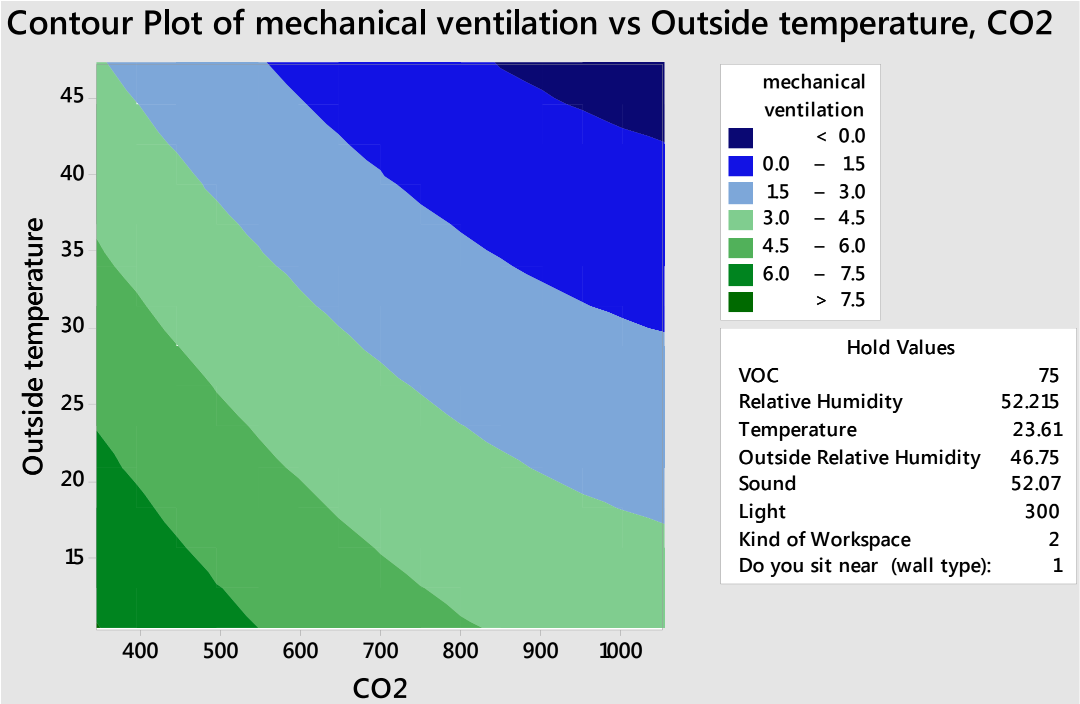


Figure 4.85 Contour Plot - Effect of Outside Temperature, Carbon Dioxide on Air Comfort (Mech. Vent.)

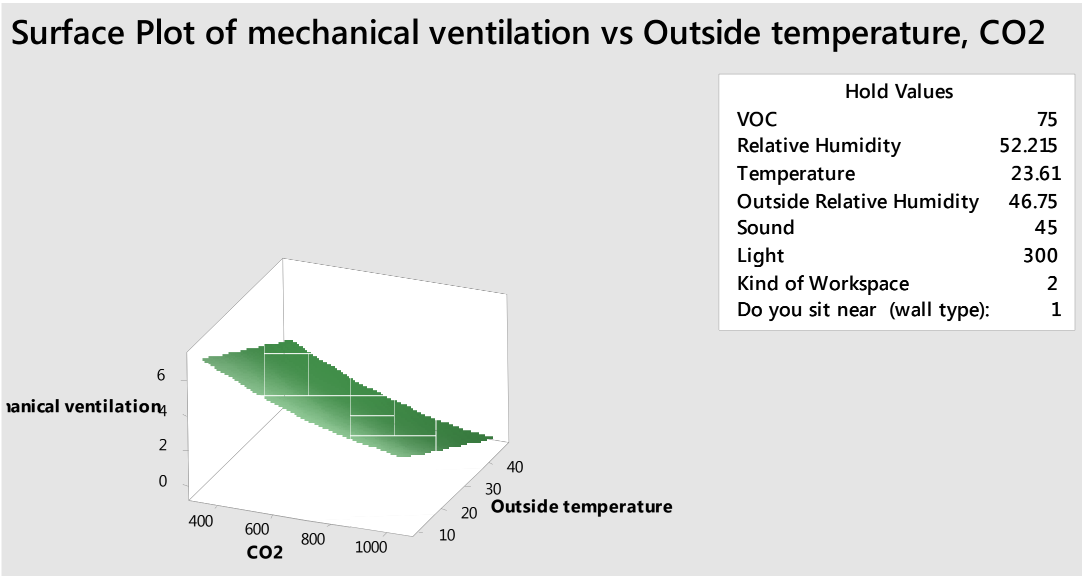


Figure 4.86 - Surface Plot - Effect of Outside Temperature, Carbon Dioxide on Air Comfort (Mech. Vent.)

4.4.6.13 Effect of Temperature, Carbon Dioxide on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

These contour and surface plots (Figure 4.87, Figure 4.88) outline the following:

- Carbon dioxide has a significant impact on indoor air quality and productivity. Optimum levels are observed up to 450 ppm.
- Plots indicate the temperature does not have any significant effect on indoor air comfort.

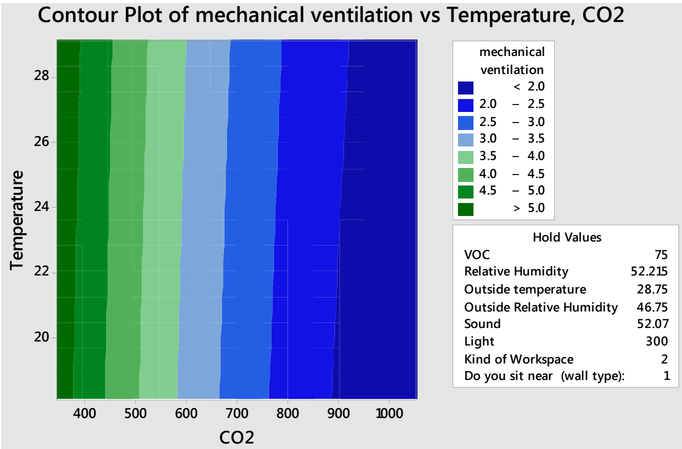


Figure 4.87 Contour Plot - Effect of Temperature, Carbon Dioxide on Air Comfort (Mech. Vent.)

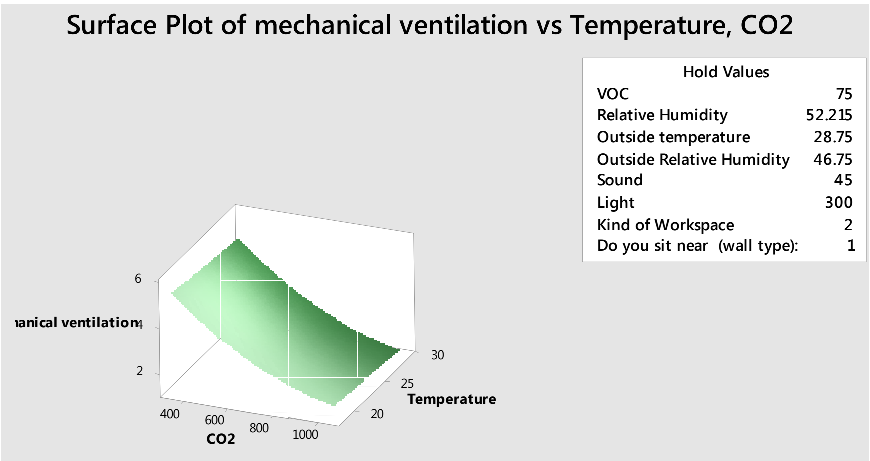


Figure 4.88 Surface Plot - Effect of Temperature, Carbon Dioxide on Air Comfort (Mech. Vent.)

4.4.6.14 Effect of Relative Humidity, Carbon Dioxide on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

The plot lines below (Figure 4.89, Figure 4.90) outline the following:

- Carbon dioxide has a significant impact on indoor air quality, hence on occupant comfort and productivity. Optimum levels are observed below 550 ppm.
- Between the relative humidity and carbon dioxide, relative humidity does not have a significant impact on indoor air comfort.

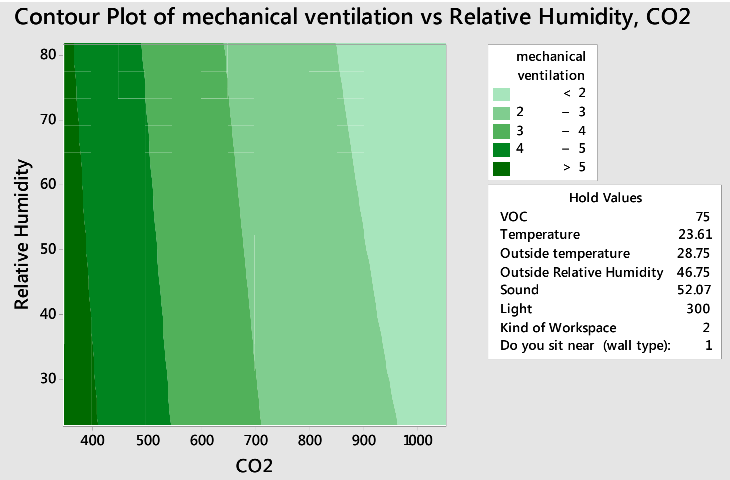


Figure 4.89 Contour Plot - Effect of Relative Humidity, Carbon Dioxide on Air Comfort (Mech. Vent)

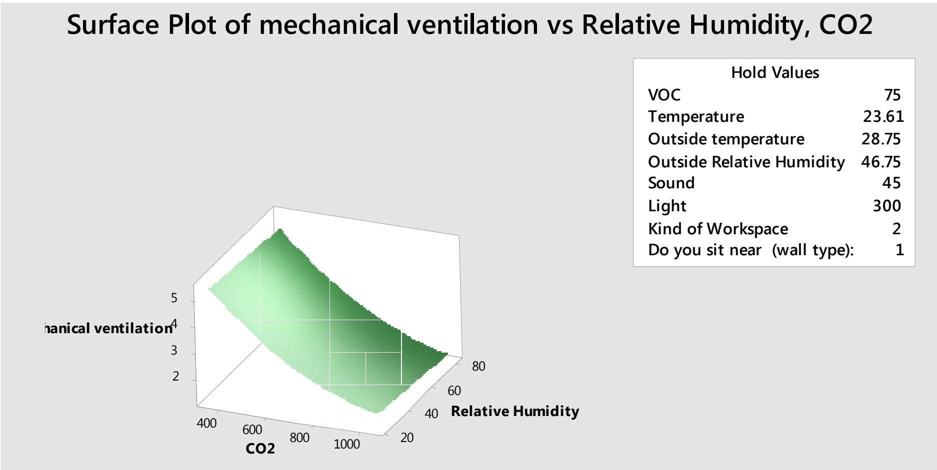


Figure 4.90 - Surface Plot - Effect of Relative Humidity, Carbon Dioxide on Air Comfort (Mech. Vent.)

4.4.6.15 Effect of VOC, Carbon Dioxide on Indoor Air Comfort (Mechanical Ventilation) and its impact on Productivity

The contour and surface plots below (Figure 4.91, Figure 4.92) highlight the following:

- Carbon dioxide has a significant impact on indoor air quality as compared to VOC. Optimum levels of carbon dioxide are 500 ppm.
- Between VOC carbon dioxide, VOC has a less significant effect on indoor air quality.

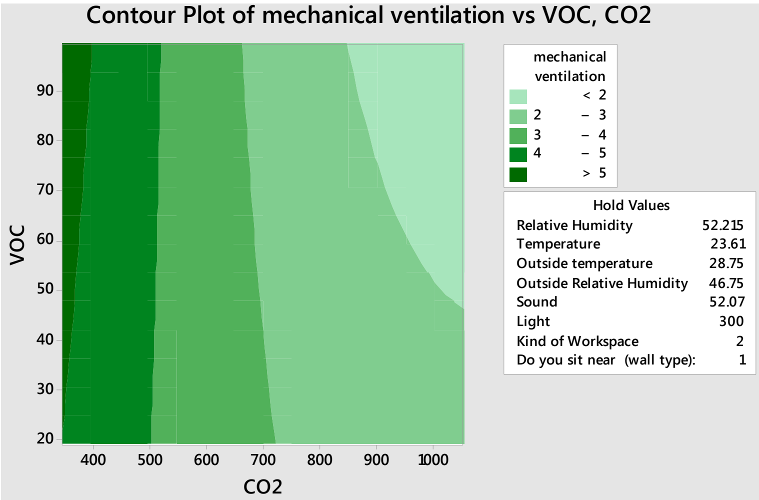


Figure 4.91 Contour Plot - Effect of VOC, Carbon Dioxide on Air Comfort (Mechanical Ventilation)

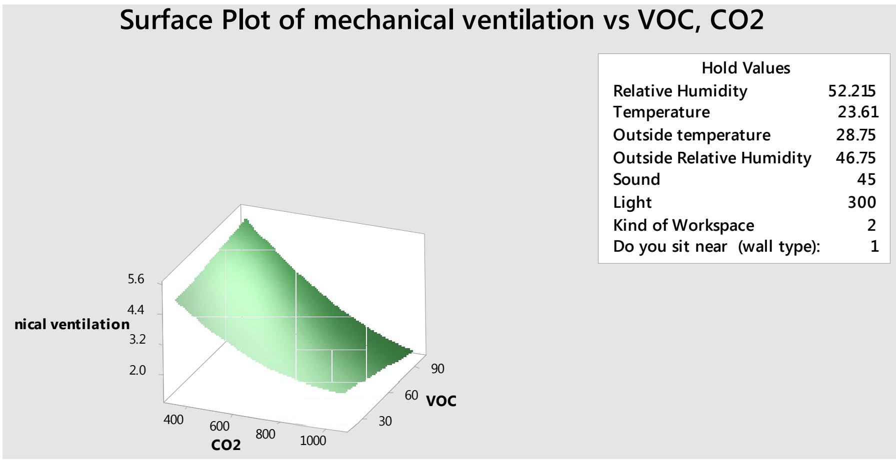


Figure 4.92 - Surface Plot - Effect of VOC, Carbon Dioxide on Air Comfort (Mechanical Ventilation)

4.4.7 <u>Summary</u>

This question was aimed at identifying the influence of various physical environmental parameters on an occupant's air comfort (mechanical ventilation) and their impact on productivity. Here are the primary results of the analysis:

1. Carbon dioxide has a maximum effect on the occupant's air comfort and also on productivity.
2. Among other parameters, VOC, outside temperature, outside relative humidity and light are observed to have a direct or indirect influence on indoor air comfort and occupant productivity.
3. Optimum comfort and productivity ranges are:
    a. Sound – 45-55 dB
    b. Relative Humidity – below 60%
    c. Carbon Dioxide – below 500 ppm
    d. VOC – Above 75% VOC free air
    e. Outside temperature – below 36°c
    f. Outside Relative Humidity: below 60%

4.5 Response Surface Regression for Indoor Air Comfort (VOC) and Productivity

A response surface analysis of indoor air comfort was conducted to identify the input variables that influence an occupant's perception of air freshness and VOC present, observing how it affects their productivity. It revealed the following:

- P-values for the independent factors their square and 2-way interactions
- R-square (coefficient of determination)
- Residual Plots
- Regression equation
- Pareto chart
- Contour plots
- Surface Plots

4.5.1 Analysis of Variance

Source	DF	Adj SS	Adj MS	P-Value
Model	25	483.334	19.333	0.000
Linear	1	110.159	110.159	0.000
VOC	1	110.159	110.159	0.000
Square	3	7.418	2.473	0.000
Relative Humidity*Relative Humidity	1	0.930	0.930	0.037
Sound*Sound	1	0.770	0.770	0.058
VOC*VOC	1	6.123	6.123	0.000
2-Way Interaction	21	18.039	0.859	0.000
Outside temperature*Light	1	0.812	0.812	0.052

Outside Relative Humidity*CO2	1	2.470	2.470	0.001
Outside Relative Humidity*VOC	1	1.883	1.883	0.003
Outside Relative Humidity*Do you sit near (wall type):	3	1.531	0.510	0.068
Sound*Light	1	1.487	1.487	0.009
Sound*Do you sit near (wall type):	3	1.739	0.580	0.045
CO2*VOC	1	1.673	1.673	0.005
CO2*Do you sit near (wall type):	3	3.093	1.031	0.003
Light*Kind of Workspace	4	2.787	0.697	0.012
VOC*Do you sit near (wall type):	3	2.494	0.831	0.009
Error	339	72.266	0.213	
Lack-of-Fit	335	71.266	0.213	0.678
Pure Error	4	1.000	0.250	
Total	364	555.600		

Table 4.4 - Analysis of Variance - VOC

The experiment was based on the following hypothesis,

- H_0 = Variable has no effect on occupant's indoor air comfort (air freshness and VOC) and its impact on productivity.
- H_{alt} = Variable has an effect on occupant's indoor air comfort (air freshness and VOC) and its impact on productivity.

The ANOVA is done using a=0.1.

If p-value ≥ 0.1, it indicates strong evidence of null hypothesis.

If p-value ≤ 0.1, it indicates strong evidence against the null hypothesis, hence rejecting the null hypothesis.

Based on the ANOVA, the following factors influence an occupant's air comfort (presence of toxin) and its impact on the productivity of occupants (Table 4.4):

1. VOC
2. Relative Humidity*Relative Humidity
3. VOC*VOC
4. CO^2*CO^2
5. Outside Temperature*Light
6. Outside Relative Humidity*CO^2
7. Outside Relative Humidity*VOC
8. VOC*Wall type
9. Sound*Light
10. CO^2*Wall type

It can be observed that the above factors affect indoor air comfort both directly and indirectly. All of these factors have a different magnitude of influence, which is further discussed/ explained in Pareto charts.

4.5.2 <u>The Coefficient of Determination (Multiple Correlation Coefficient)</u>

The coefficient of determination (adjusted R-square) value is 86.03%. This indicates that 86% of the data fits the regression and there is a significant relationship between dependent and independent variables.

4.5.3 Residual Plots

Residual plots are used to determine the fit of model data (Figure 4.93).

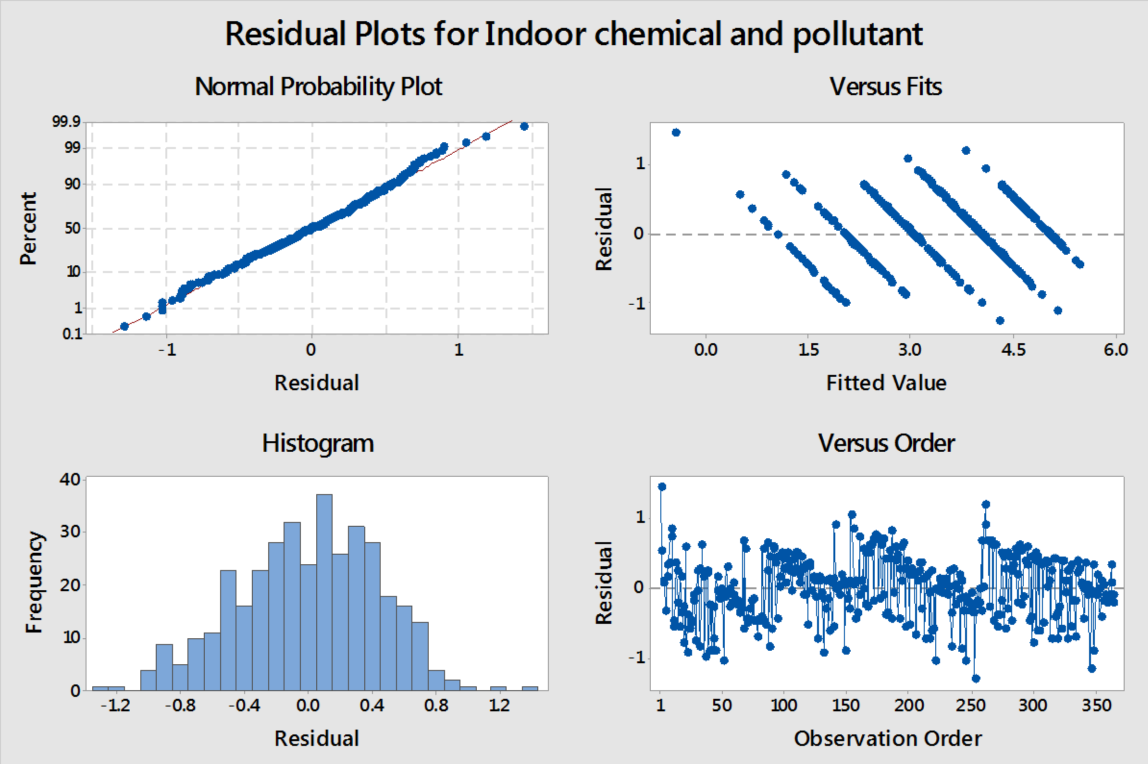


Figure 4.93 - Residual Plots - VOC

4.5.3.1 Normal probability plot

The residuals in the figure above mostly follow the expected values (mainline). This indicates that residuals are normally distributed.

4.5.3.2 Versus fits of fitted value plot

The scatter of the residuals varies as the fitted value increases. It indicates that residuals are unequal.

4.5.3.3 Residual Histogram

The histogram figure above is observed to be closely shaped like a U- shaped histogram with few outliers. It indicates that the data is normally distributed.

4.5.3.4 Residual versus order plot

Residuals in the above figure are between -1 to 1 and suggest no direct pattern. It indicates that regression assumptions are satisfied.

4.5.4 Regression Equation

Indoor chemical and pollutant = 2.5775 + 3.968 VOC
- 0.289 Relative Humidity*Relative Humidity
+ 0.237 Sound*Sound - 0.930 VOC*VOC
- 0.343 Outside temperature*Light
+ 0.412 Outside Relative Humidity*CO2
+ 0.459 Outside Relative Humidity*VOC-
0.214 Outside Relative Humidity*Do you sit near (wall type):_1-
0.0560 Outside Relative Humidity*Do you sit near (wall typ
e):_2+ 0.037 Outside Relative Humidity*Do you sit near (wall typ
e):_3+ 0.2335 Outside Relative Humidity*Do you sit near (wall typ
e):_4 + 0.470 Sound*Light
+ 0.209 Sound*Do you sit near (wall type):_1
+ 0.147 Sound*Do you sit near (wall type):_2
- 0.073 Sound*Do you sit near (wall type):_3
- 0.283 Sound*Do you sit near (wall type):_4 + 0.400 CO2*VOC
+ 0.083 CO2*Do you sit near (wall type):_1
- 0.3182 CO2*Do you sit near (wall type):_2
+ 0.159 CO2*Do you sit near (wall type):_3
+ 0.076 CO2*Do you sit near (wall type):_4
- 0.534 Light*Kind of Workspace_1
+ 0.310 Light*Kind of Workspace_2
- 0.055 Light*Kind of Workspace_3
- 0.188 Light*Kind of Workspace_4
+ 0.466 Light*Kind of Workspace_5
+ 0.215 VOC*Do you sit near (wall type):_1
- 0.362 VOC*Do you sit near (wall type):_2
+ 0.277 VOC*Do you sit near (wall type):_3
- 0.131 VOC*Do you sit near (wall type):_4

4.5.4.1 Equation explanation

The regression equation shows various variables that have an effect on occupant's indoor air comfort and impact on productivity. It indicates that VOC, carbon dioxide, sound and outside relative humidity have an influence on an occupant's indoor air comfort and also on their productivity. Along with the factors mentioned above, few more linear, square and interactions contribute to the final output.

As part of the analysis, various types of graphs have been used to show the impact of different input variables on the output variables.

4.5.5 Pareto chart

The Pareto chart represents the independent variable's magnitude of effect on the output variable (Figure 4.94). The chart has set 1.65 (Standardized Effect) as the reference line to identify the variables that affect occupant's indoor air comfort and its impact on productivity.

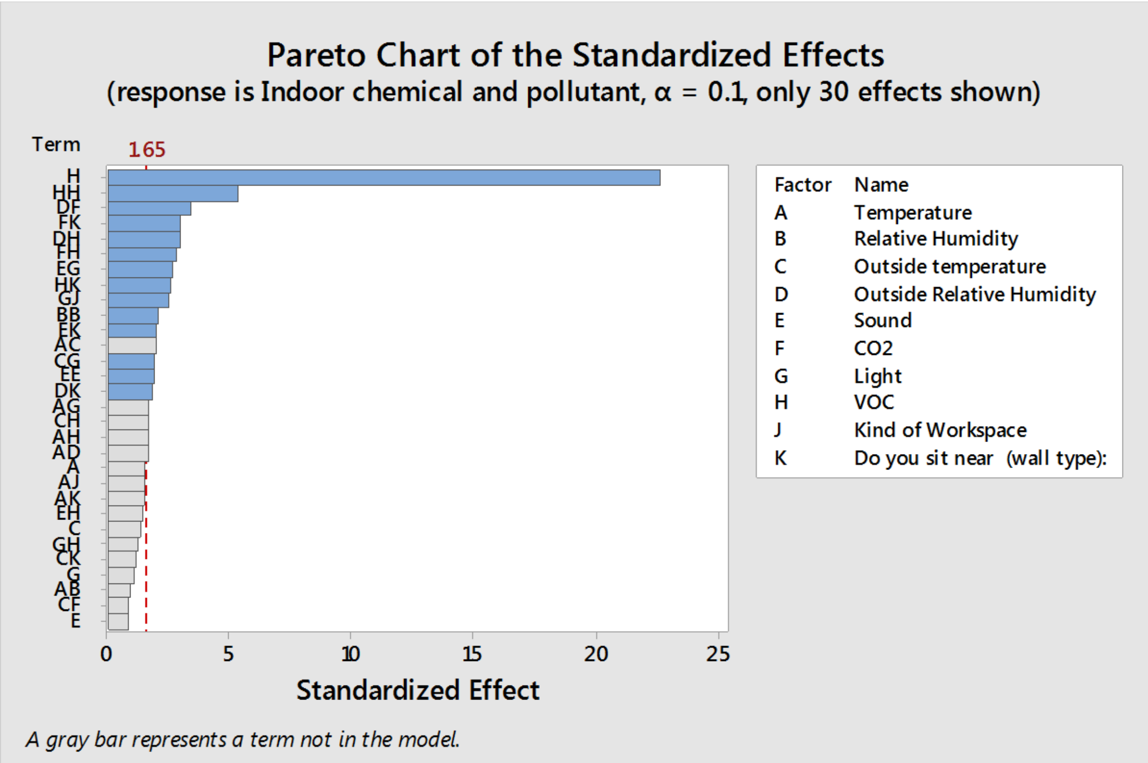


Figure 4.94 - Pareto Chart – VOC

The chart shows that the following variables have a significant effect:

1. VOC
2. VOC*VOC
3. Outside Relative Humidity*Carbon Dioxide
4. Carbon Dioxide*Wall type
5. Outside Relative Humidity*VOC
6. Sound*VOC
7. Sound*Light
8. VOC*Wall type

4.5.6 Contour and Surface Plots

Contour and surface plots have been created to identify optimal results by showing the effect of two independent variables on the dependent variable. The researcher has only discussed the plots that show significant impacts on indoor air comfort and its impact on productivity.

4.5.6.1 Effect of light, VOC on Occupant's Indoor Air Comfort (VOC) and its impact on Productivity

Below contour and surface plots (Figure 4.95, Figure 4.96) highlight the following:

- VOC has a direct effect on occupant's air comfort and productivity. Optimum range is 70% VOC free air and above.
- Light does not have any significant effect on occupant's air comfort and productivity.

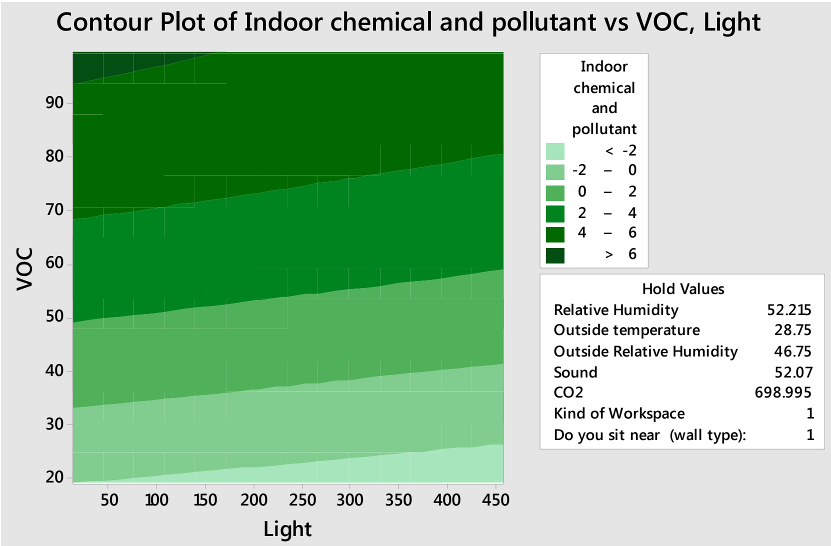


Figure 4.95 Contour Plot - Effect of light, VOC on Occupant's Air Comfort (VOC)

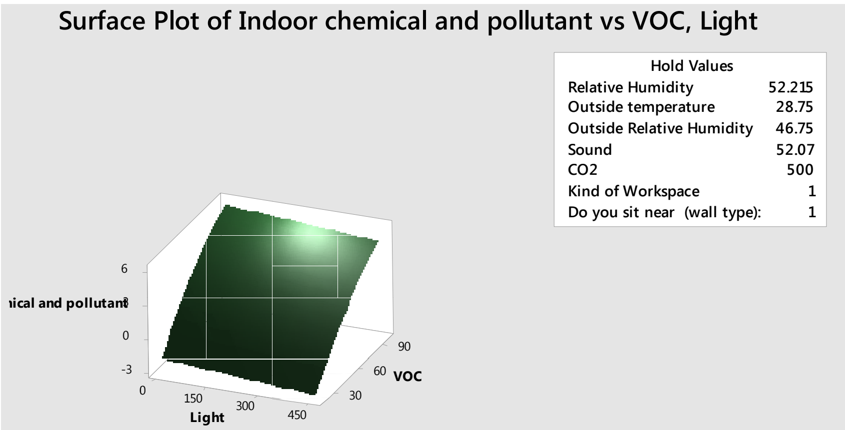


Figure 4.96 - Surface Plot - Effect of light, VOC on Occupant's Air Comfort (VOC)

4.5.6.2 Effect of Carbon Dioxide, VOC on Occupant's Indoor Air Comfort (VOC) and its impact on Productivity

Below show contour and surface plot lines (Figure 4.97, Figure 4.98) that present the following:

- VOC has a direct impact on occupant's indoor air comfort. The optimum level is 80% VOC free air and above.
- Between Carbon Dioxide and VOC, carbon dioxide does not have a significant impact on indoor air comfort and occupant's perception of toxins and also on productivity.

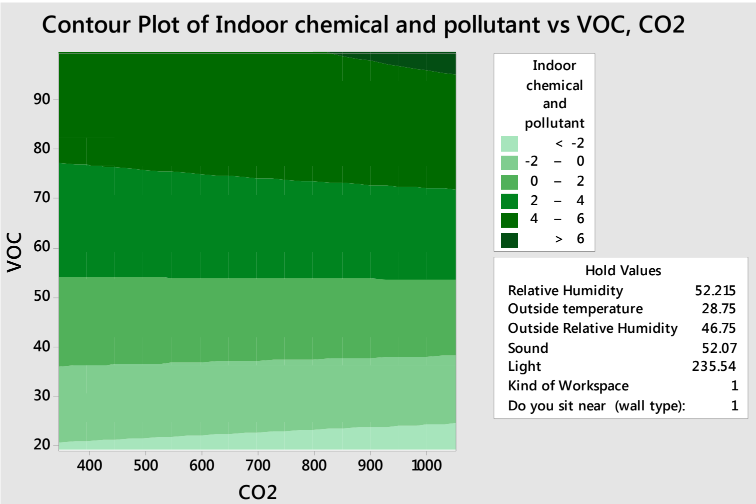


Figure 4.97 Contour Plot - Effect of Carbon Dioxide, VOC on Occupant's Indoor Air Comfort (VOC)

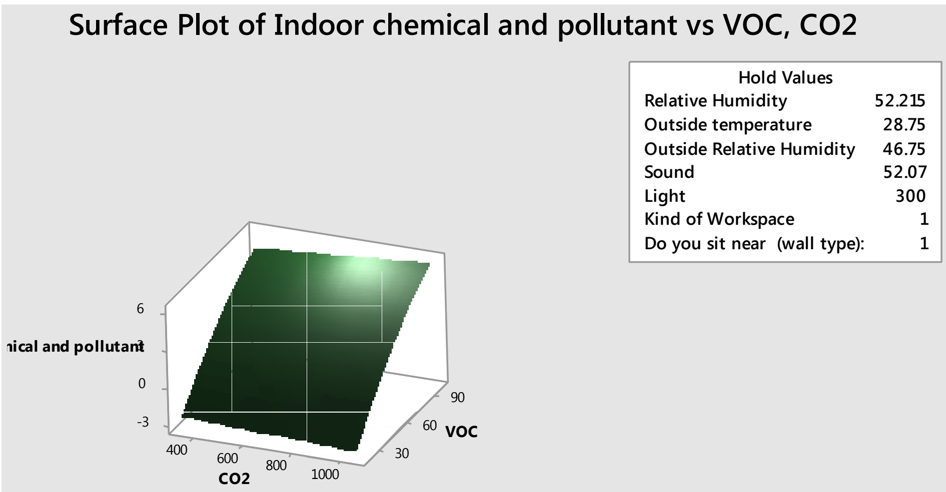


Figure 4.98 Surface lot - Effect of Carbon Dioxide, VOC on Occupant's Air Comfort (VOC)

4.5.6.3 Effect of Sound, VOC on Occupant's Indoor Air Comfort (VOC) and its impact on Productivity

The contour and surface plot lines, below, (Figure 4.99, Figure 4.100) outline the following:

- VOC has a direct effect on an occupant's indoor air comfort. The optimum level is 75% VOC free air and above.
- Sound does not have a direct impact on indoor air comfort and productivity.

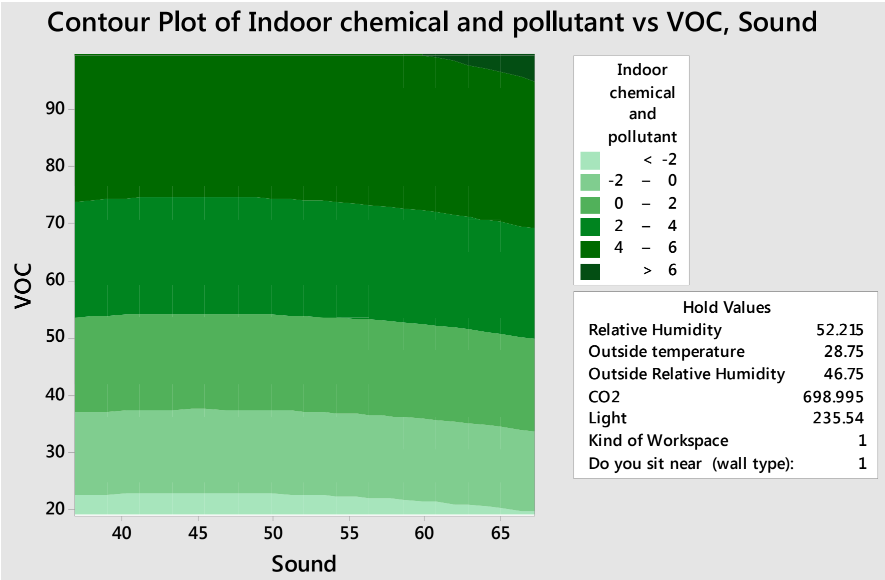


Figure 4.99 - Contour Plot - Effect of Sound, VOC on Occupant's Air Comfort (VOC)

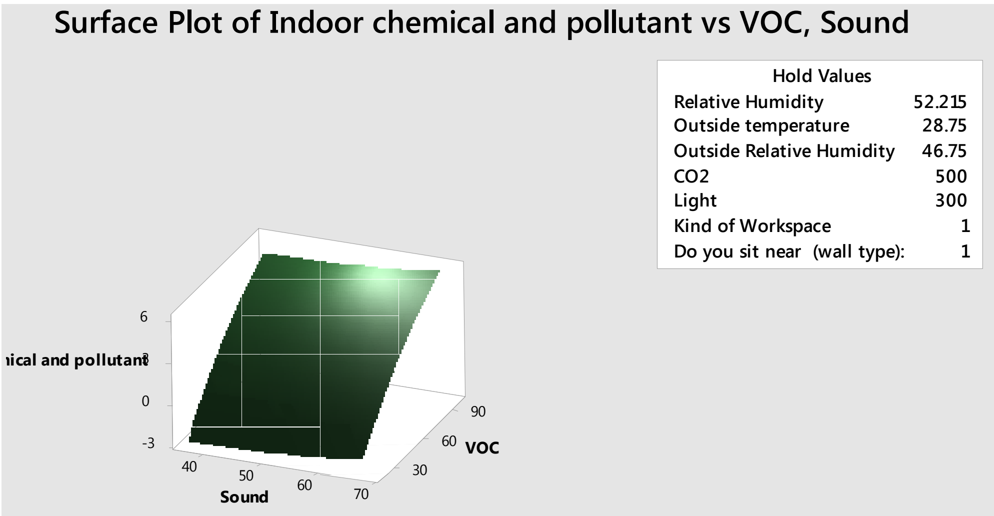


Figure 4.100 - Surface Plot - Effect of Sound, VOC on Occupant's Air Comfort (VOC)

4.5.6.4 Effect of outside Relative Humidity, VOC on Occupant's Indoor Air Comfort (VOC) and its impact on Productivity

These charts show that (Figure 4.101Figure 4.102):

- VOC has a direct impact on occupant's indoor air comfort. The optimum level is 75% VOC free air and above.
- Between Outside Relative Humidity and VOC, Outside Relative Humidity has no perceivable impact on occupant's indoor air comfort (toxins) and its impact on productivity.

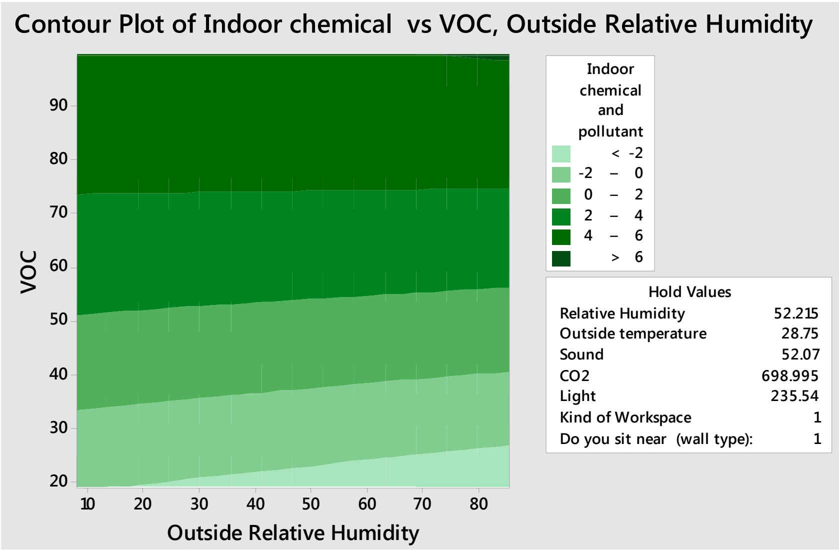


Figure 4.101 - Contour Plot - Effect of outside R.H., VOC on Occupant's Air Comfort (VOC)

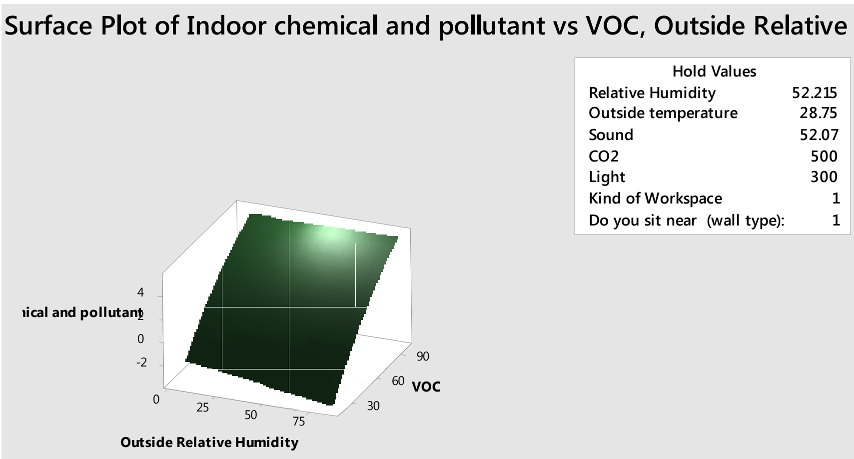


Figure 4.102 - Surface Plot - Effect of outside R.H., VOC on Occupant's Air Comfort (VOC)

4.5.6.5 Effect of outside Relative Humidity, Carbon Dioxide on Occupant's Indoor Air Comfort (VOC) and its impact on Productivity

Below, the plot lines present the following:

- Carbon Dioxide has a significant impact on occupant's air comfort and productivity. Maximum levels of productivity are observed at 450 ppm and below.
- Between outside relative humidity and carbon dioxide, outside relative humidity has no significant impact on air comfort and productivity.

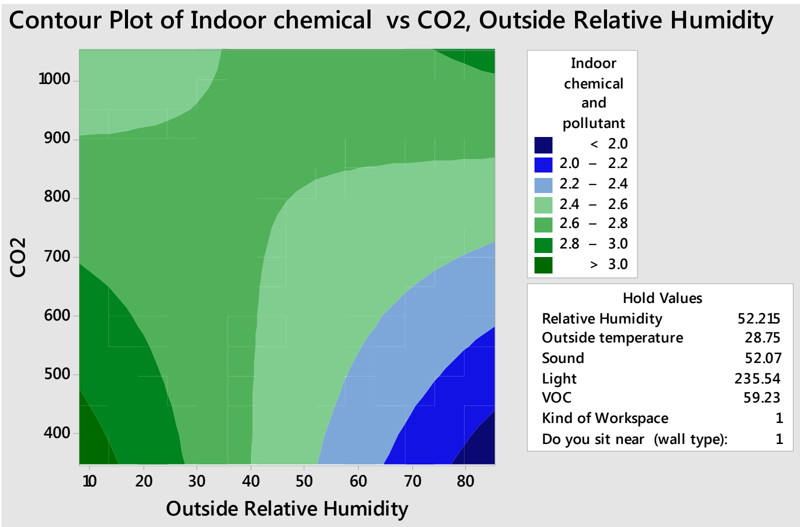


Figure 4.103 – Contour Plot - Effect of outside R.H., Carbon Dioxide on Occupant's Air Comfort (VOC)

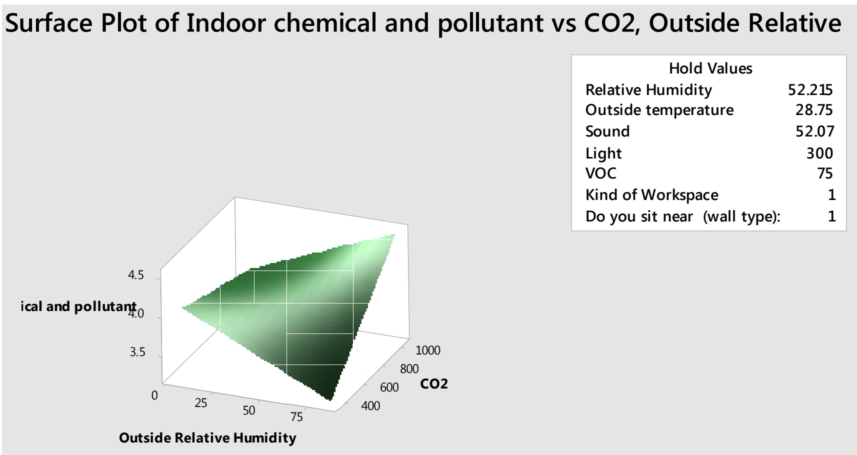


Figure 4.104 Surface Plot - Effect of outside R.H., Carbon Dioxide on Occupant's Air Comfort (VOC)

4.5.6.6 Effect of outside Relative Humidity, Carbon Dioxide on Occupant's Indoor Air Comfort (VOC) and its impact on Productivity

These graphs demonstrate that:

- VOC has a direct effect on occupant air comfort and productivity. The optimum range of VOC is observed to be 75% VOC free air and above.
- Between VOC and outside temperature, outside temperature has no significant impact on occupant's air comfort and productivity.

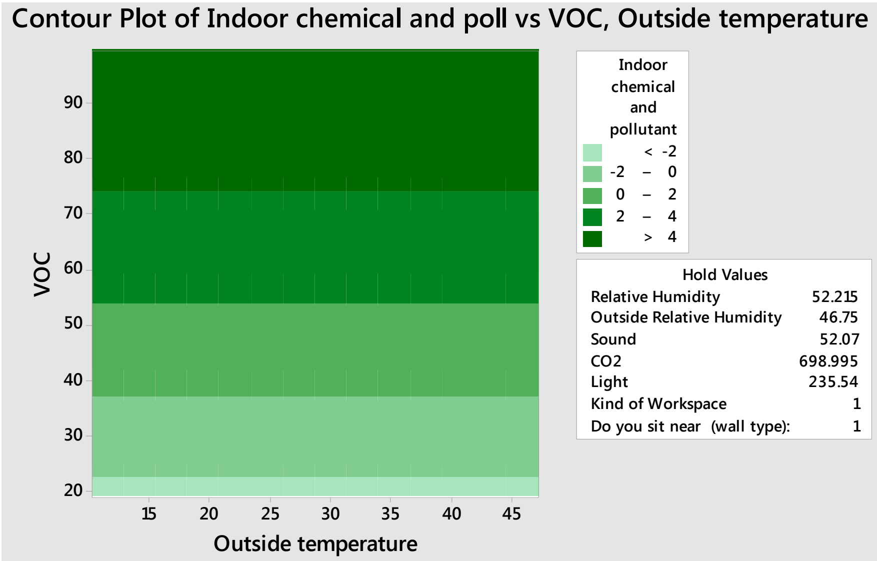


Figure 4.105 - Contour Plot - Effect of outside R.H., Carbon Dioxide on Occupant's Air Comfort (VOC)

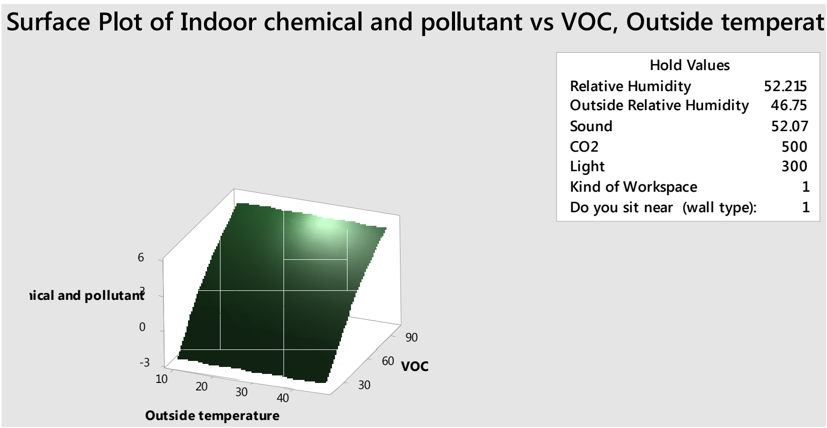


Figure 4.106 - Surface Plot - Effect of outside R.H., Carbon Dioxide on Occupant's Air Comfort (VOC)

4.5.6.7 Effect of VOC, Relative Humidity on Occupant's Indoor Air Comfort (VOC) and its impact on Productivity

In these charts, we can see that:

- VOC has a significant effect on occupant's indoor air comfort and its impact on productivity.
- Relative humidity does not affect occupant's indoor air comfort and productivity.

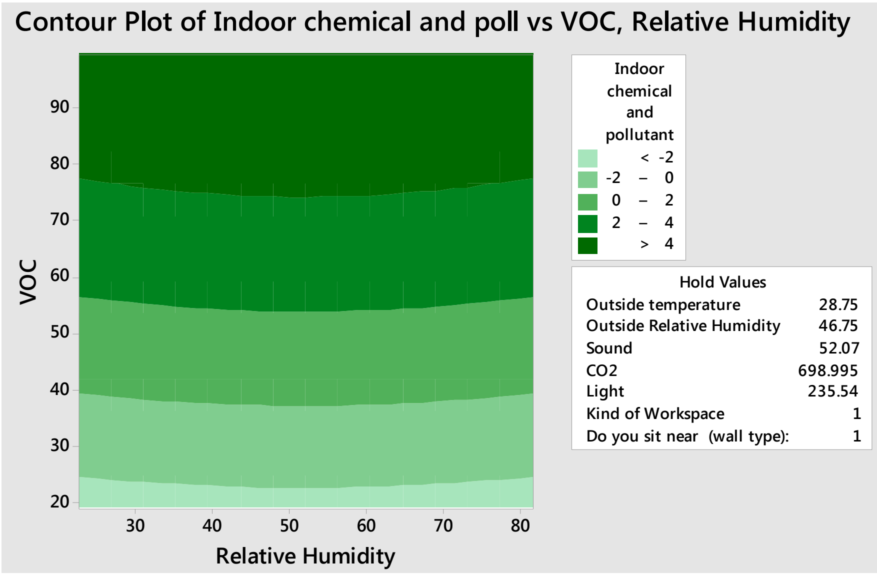


Figure 4.107 - Contour Plot - Effect of VOC, Relative Humidity on Occupant's Indoor Air Comfort (VOC)

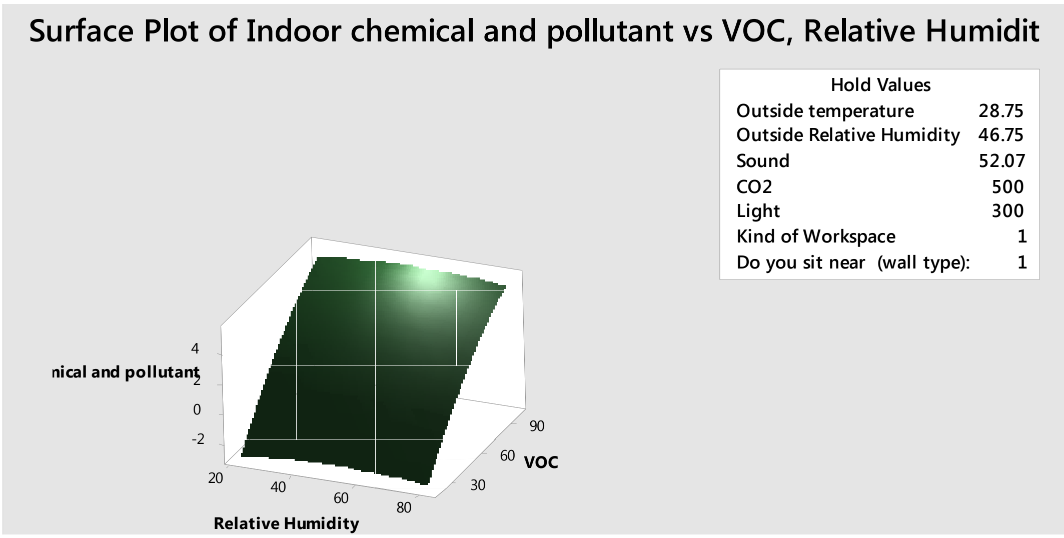


Figure 4.108 - Surface Plot Effect of VOC, Relative Humidity on Occupant's Indoor Air Comfort (VOC)

4.5.7 <u>Summary</u>

This question was aimed to identify the influence of various physical environmental parameters on an occupant's air comfort (VOC) and their impact on productivity. The main results from the analysis are that:

1. VOC has a maximum and direct effect on an occupant's air comfort and productivity.
2. Among other parameters, carbon dioxide and outside relative humidity also have some impact on occupant air comfort levels and impact on their productivity.
3. Optimum range:
    a. VOC – 75% VOC free air and above.
    b. Carbon Dioxide – 450 ppm and below.

4.6 Response Surface Regression analysis for Acoustic Comfort and Productivity

A response surface analysis of acoustic comfort was carried out to identify the input variables that influence an occupant's acoustic comfort and how it affects their productivity. It produced the following:

- P-values for the independent factors their square and 2-way interactions
- R square (coefficient of determination)
- Residual Plots
- Regression equation
- Pareto Chart
- Contour plots
- Surface Plots
- Summary

4.6.1 Analysis of Variance

Source	DF	Adj SS	Adj MS	P-Value
Model	37	436.749	11.804	0.000
Linear	14	195.276	13.948	0.000
Sound	1	129.971	129.971	0.000
Light	1	0.894	0.894	0.036
VOC	1	3.310	3.310	0.000
Temperature	1	2.190	2.190	0.001
Outside temperature	1	0.415	0.415	0.153
Outside Relative Humidity	1	1.624	1.624	0.005
CO2	1	0.064	0.064	0.573

Kind of Workspace	4	1.134	0.283	0.233
Do you sit near (wall type):	3	0.463	0.154	0.515
Square	3	15.545	5.182	0.000
Sound*Sound	1	14.838	14.838	0.000
VOC*VOC	1	1.740	1.740	0.004
Temperature*Temperature	1	3.171	3.171	0.000
2-Way Interaction	20	12.839	0.642	0.000
Sound*VOC	1	1.312	1.312	0.011
Sound*Temperature	1	1.127	1.127	0.019
Light*CO2	1	1.818	1.818	0.003
VOC*Temperature	1	0.797	0.797	0.048
Temperature*Kind of Workspace	4	2.799	0.700	0.009
Outside temperature*Outside Relative Humidity	1	0.709	0.709	0.062
Outside temperature*Kind of Workspace	4	1.940	0.485	0.050
Outside Relative Humidity*Kind of Workspace	4	2.705	0.676	0.011
Outside Relative Humidity*Do you sit near (wall type):	3	2.012	0.671	0.020
Error	327	66.057	0.202	
Lack-of-Fit	323	65.557	0.203	0.349
Pure Error	4	0.500	0.125	
Total	364	502.805		

Table 4.5 - Analysis of Variance - Acoustic Comfort

The experiment was based on the following hypothesis,

- H_0 = Variable does not affect occupant's acoustic comfort and its impact on productivity.
- H_{alt} = Variable affects occupant's acoustic comfort and its impact on productivity.

The ANOVA is done using a=0.1.

If p-value ≥ 0.1, it indicates strong evidence of null hypothesis.

If p-value ≤ 0.1, it indicates strong evidence against the null hypothesis, hence rejecting the null hypothesis.

Based on the ANOVA, the following factors affect occupant's acoustic comfort and its impact on the productivity of occupants (Table 4.5):

1. Sound
2. Light
3. VOC
4. Temperature
5. Outside Relative Humidity
6. Sound*Sound
7. VOC*VOC
8. Sound*VOC
9. Sound*Temperature
10. Light*CO^2
11. VOC*Temperature
12. Temperature*Type of Workspace

The above factors affect acoustic comfort both directly and indirectly. All of these factors have a different magnitude of influence. The level of magnitude would be highlighted in Pareto charts.

4.6.2 The Coefficient of Determination (Multiple Correlation Coefficient)

Coefficient of determination (adjusted R-square) value is 85.38%. It indicates that 85% of the data fits the regression and there is a significant relationship between dependent and independent variables.

4.6.3 Residual Plots

Residual plots are used to determine the fit of model data. Below are the residual plots for Acoustic quality.

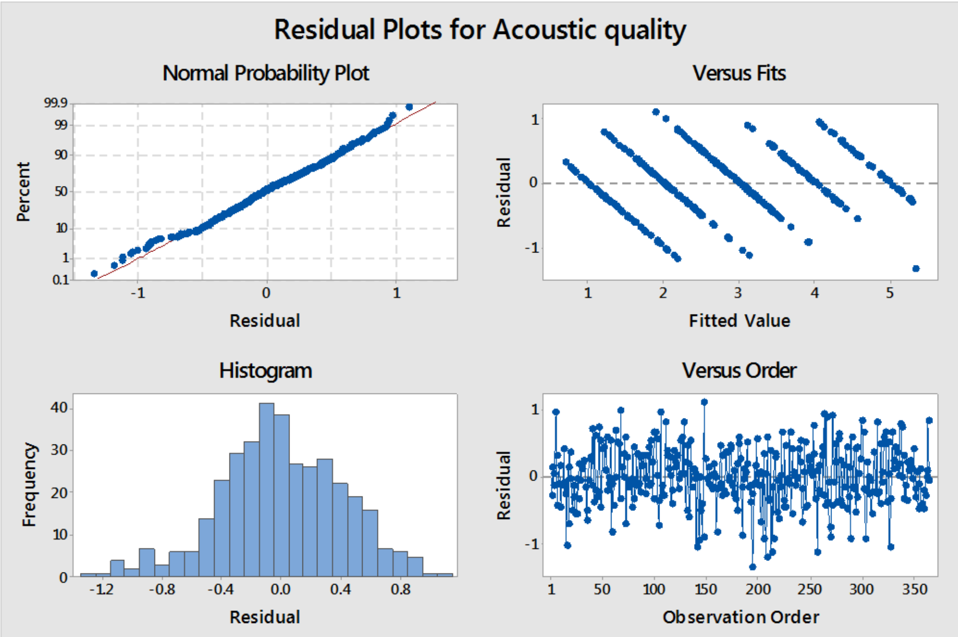


Figure 4.109 – Residual Plots – Acoustic Quality

4.6.3.1 Normal Probability Plot

The residuals in the figure above follow the expected values (mainline). It indicates that residuals are normally distributed.

4.6.3.2 Versus Fits of Fitted Value Plot

The scatter of the residuals varies as the fitted value increases. It indicates that the residuals are unequal.

4.6.3.3 Residual Histogram

The histogram figure above is observed to be spread over a central area. It is a wide U-shaped histogram with few outliers. It indicates that data is normally distributed.

4.6.3.4 Residual versus Order Plot

Residuals in the above figure are between -1 to 1 and suggest no pattern. It indicates that regression assumptions are satisfied.

4.6.4 Regression Equation

Acoustic quality = 26.65 - 0.5323 Sound + 0.00348 Light + 0.0509 VOC - 0.890 Temperature
+ 0.0427 Outside temperature + 0.02693 Outside Relative Humidity
+ 0.001642 CO2 + 2.87 Kind of Workspace_1 - 0.222 Kind of Workspace_2
+ 0.193 Kind of Workspace_3 - 1.77 Kind of Workspace_4
- 1.07 Kind of Workspace_5 - 0.504 Do you sit near (wall type):_1
+ 0.309 Do you sit near (wall type):_2
+ 0.267 Do you sit near (wall type):_3
- 0.073 Do you sit near (wall type):_4 + 0.005809 Sound*Sound
- 0.000312 VOC*VOC + 0.02229 Temperature*Temperature - 0.000809 Sound*VOC
- 0.00700 Sound*Temperature - 0.000006 Light*CO2
+ 0.001758 VOC*Temperature - 0.0668 Temperature*Kind of Workspace_1
+ 0.0722 Temperature*Kind of Workspace_2
+ 0.0710 Temperature*Kind of Workspace_3
+ 0.1208 Temperature*Kind of Workspace_4
- 0.1972 Temperature*Kind of Workspace_5
- 0.000453 Outside temperature*Outside Relative Humidity
- 0.0147 Outside temperature*Kind of Workspace_1
- 0.0374 Outside temperature*Kind of Workspace_2
- 0.0373 Outside temperature*Kind of Workspace_3
- 0.0307 Outside temperature*Kind of Workspace_4
+ 0.1201 Outside temperature*Kind of Workspace_5
- 0.02028 Outside Relative Humidity*Kind of Workspace_1
- 0.00671 Outside Relative Humidity*Kind of Workspace_2
- 0.01333 Outside Relative Humidity*Kind of Workspace_3
- 0.00297 Outside Relative Humidity*Kind of Workspace_4

+ 0.0433 Outside Relative Humidity*Kind of Workspace_5
+ 0.01123 Outside Relative Humidity*Do you sit near (wall type):_1
- 0.00723 Outside Relative Humidity*Do you sit near (wall type):_2
- 0.00389 Outside Relative Humidity*Do you sit near (wall type):_3
- 0.00011 Outside Relative Humidity*Do you sit near (wall type):_4

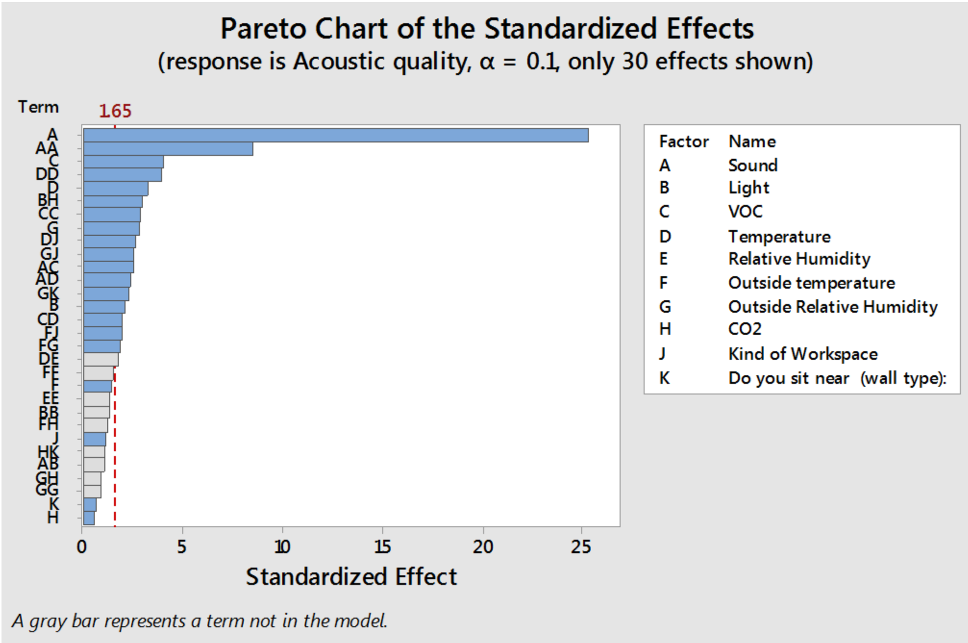
4.6.4.1 Equation Explanation

The regression equation shows various variables that affect occupant's acoustic comfort and its impact on productivity. It shows that sound levels, VOC and temperature influence an occupant's acoustic comfort and the impact on productivity. Along with the factors mentioned above, few more linear, square and interactions contribute to the final output.

As part of the analysis, various types of graphs have been used to show the impact of different input variables on the output variables.

4.6.5 Pareto Chart

A Pareto chart is used to present the independent variable's magnitude of effect on the output variable. The chart has set 1.65 (Standardized Effect) as the reference line to identify variables that have an effect on occupant visual comfort and its impact on productivity.



<u>Figure 4.110 - Pareto Chart - Acoustic Quality</u>

The following variables have a significant effect (direct and indirect) on an occupant's acoustic comfort:

1. Sound (maximum effect)
2. Sound*Sound
3. VOC
4. Temperature*Temperature
5. Temperature
6. Light*CO^2
7. VOC*VOC
8. Outside Relative Humidity
9. Temperature*Kind of Workspace
10. Outside Relative Humidity*Type of Workspace
11. Sound*VOC
12. Sound*Temperature

4.6.6 Contour and Surface Plots

Contour and surface plots have been created to identify optimal results by showing the effect of two independent variables on the dependent variable. The researcher has only discussed the plots that show important impacts on acoustic comfort and its impact on productivity.

4.6.6.1 Effect of Carbon Dioxide, Sound on Acoustic Comfort and its impact on Productivity

Below are surface and contour plot lines (Figure 4.111, Figure 4.112), which outline the following:

- Sound has a significant effect on acoustic comfort and its impact on productivity. The sound level that contributes to optimum comfort and productivity is 42dB and below.
- Carbon dioxide has no significant effect on acoustic comfort and productivity.

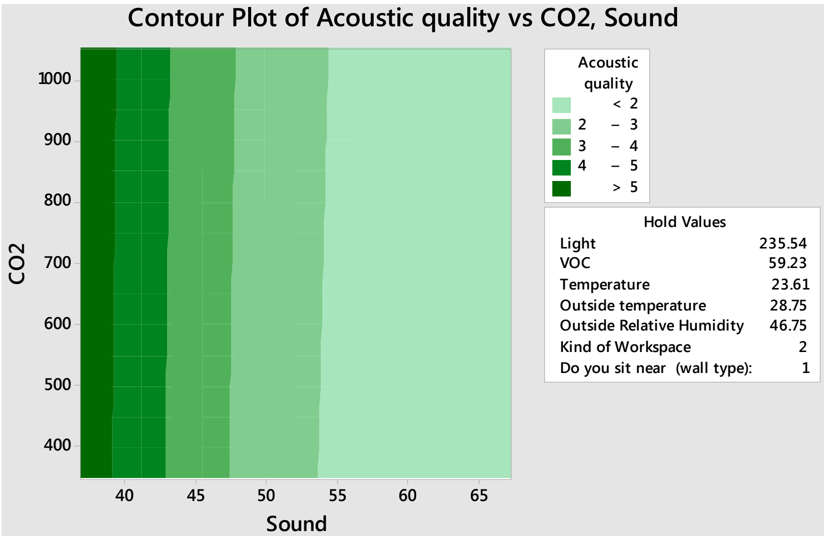


Figure 4.111 - Contour Plot - Effect of Carbon Dioxide, Sound on Acoustic Comfort

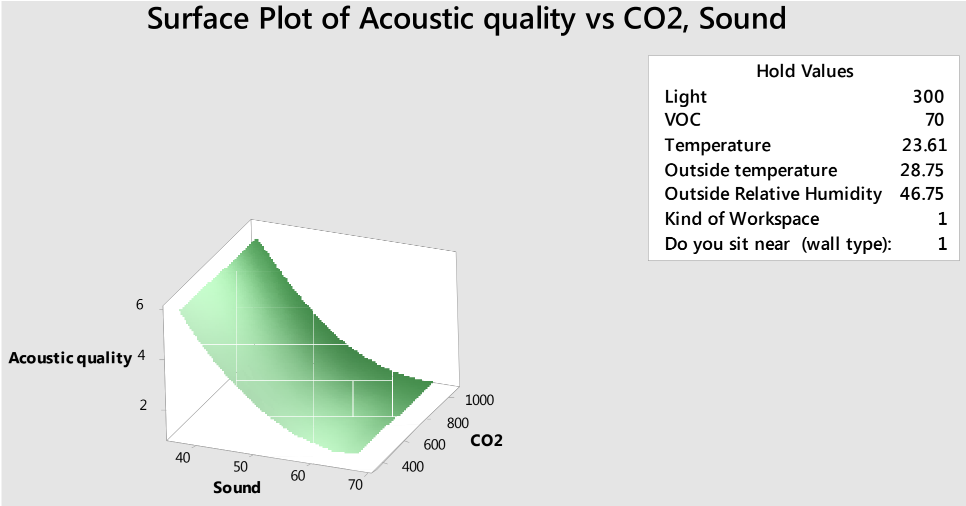


Figure 4.112 - Surface Plot - Contour Plot - Effect of Carbon Dioxide, Sound on Acoustic Comfort

4.6.6.2 Effect of outside Relative Humidity, Sound on Acoustic Comfort and its impact on Productivity

Below are contour and surface plot lines (Figure 4.113, Figure 4.114), which present the following:

- Both sound and outside relative humidity affect acoustic comfort and its impact on productivity. The optimum sound level that contributes positively to acoustic comfort and productivity is up to 45dB
- The outside relative humidity is observed to have interaction/second level effect on acoustic comfort and productivity. Low outside relative humidity has a negative impact on acoustic comfort and productivity. A plausible explanation towards this can be related to day and night time. While outside relative humidity is not directly affecting acoustic comfort. During the daytime, outside relative humidity is lower and sound levels are higher. While at night, outside relative humidity is higher and sound levels are lower. Thus, this is a correlation.

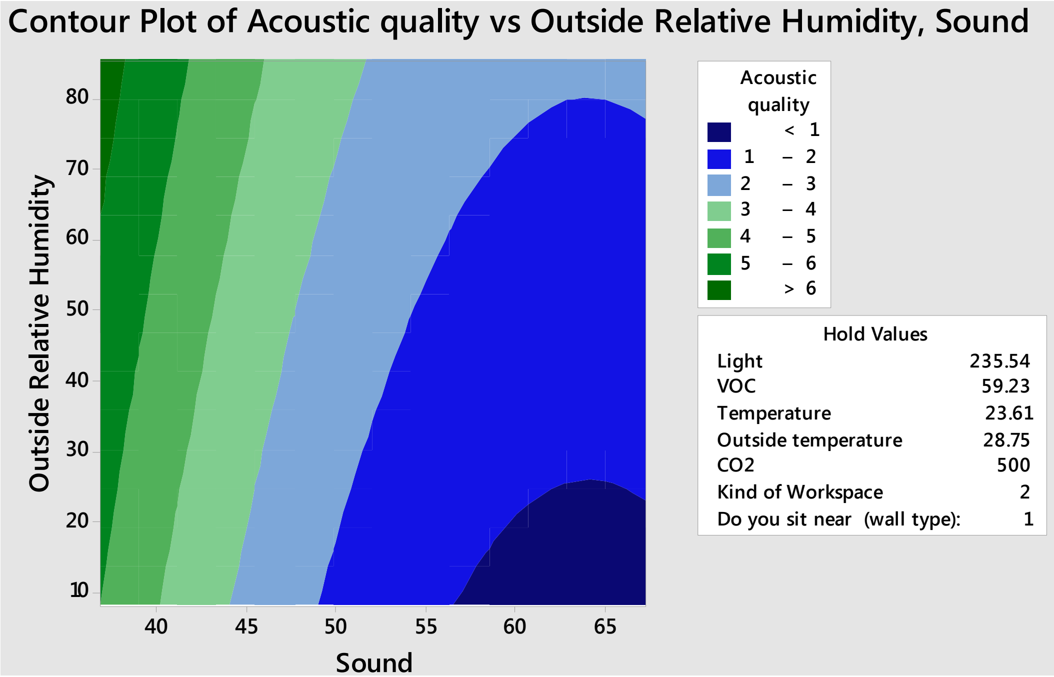


Figure 4.113 - Contour Plot - Effect of Outside R.H., Sound on Acoustic Comfort

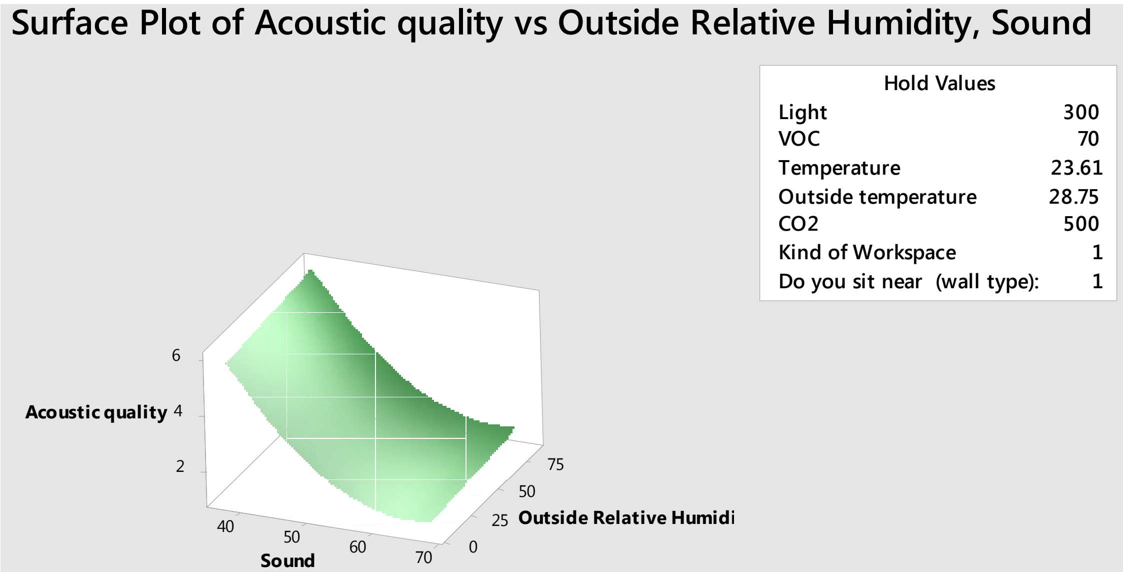


Figure 4.114 - Surface Plot - Effect of Outside R.H., Sound on Acoustic Comfort

4.6.6.3 Effect of outside Relative Humidity, Sound on Acoustic Comfort and its impact on Productivity

The contour and surface plot lines, below, (Figure 4.115, Figure 4.116) outline that:

- Sound has a significant impact on acoustic comfort. Optimum levels are up to 44dB.
- Outside temperature does not have any effect on acoustic comfort.

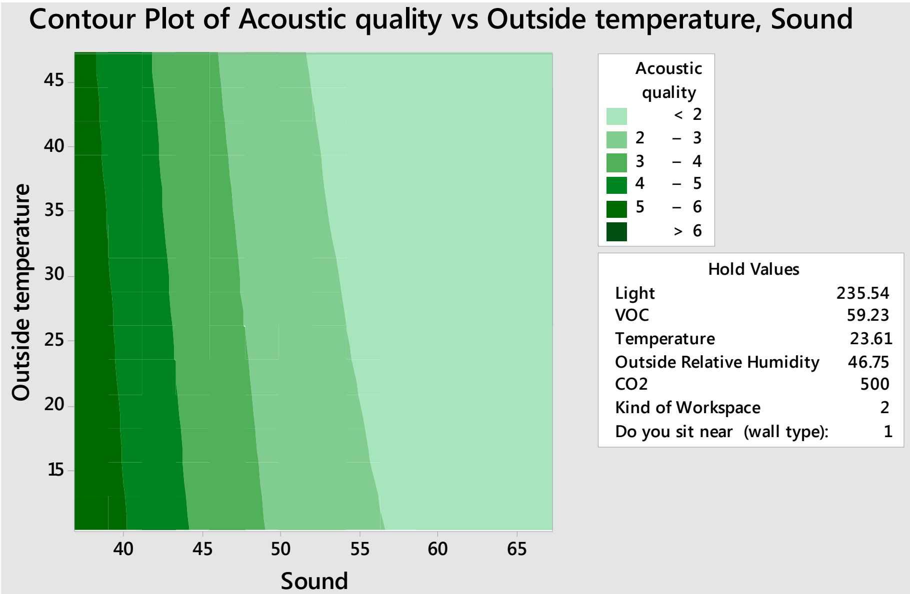


Figure 4.115 - Contour Plot - Effect of outside R.H., Sound on Acoustic Comfort

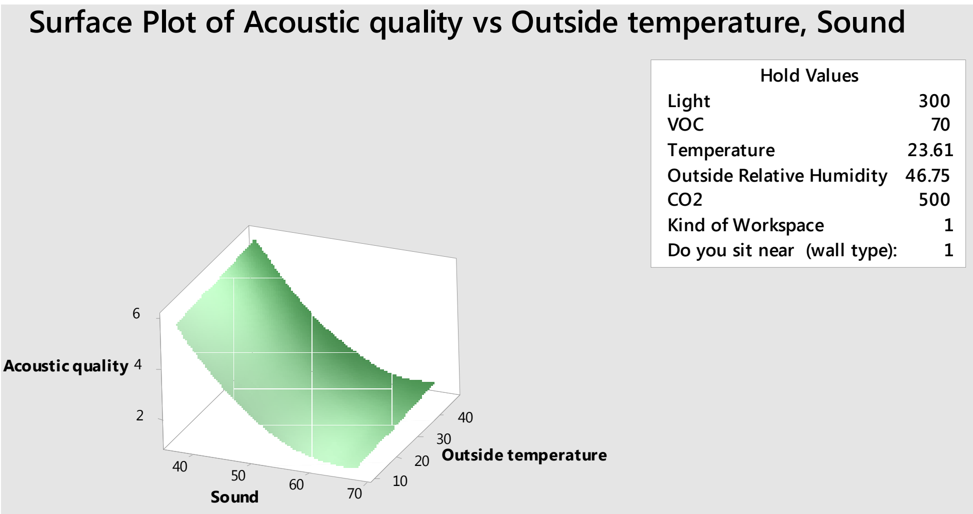


Figure 4.116 - Surface Plot - Effect of outside R.H., Sound on Acoustic Comfort

4.6.6.4 Effect of Temperature, Sound on Acoustic Comfort and its impact on Productivity

These charts (Figure 4.117, Figure 4.118) show that:

- Sound has a significant effect on acoustic comfort. Optimum levels are up to 45dB.
- Temperature does not have a direct effect on acoustic comfort, but it appears that occupants responded negatively to similar acoustic conditions when the temperature is in a comfortable range. When the temperature is on the uncomfortable side (22°c and below, 26°c and above), they tend to focus on thermal discomfort. It could be postulated that when occupants are comfortable, thermally, they tend to identify other discomforts in the environment.

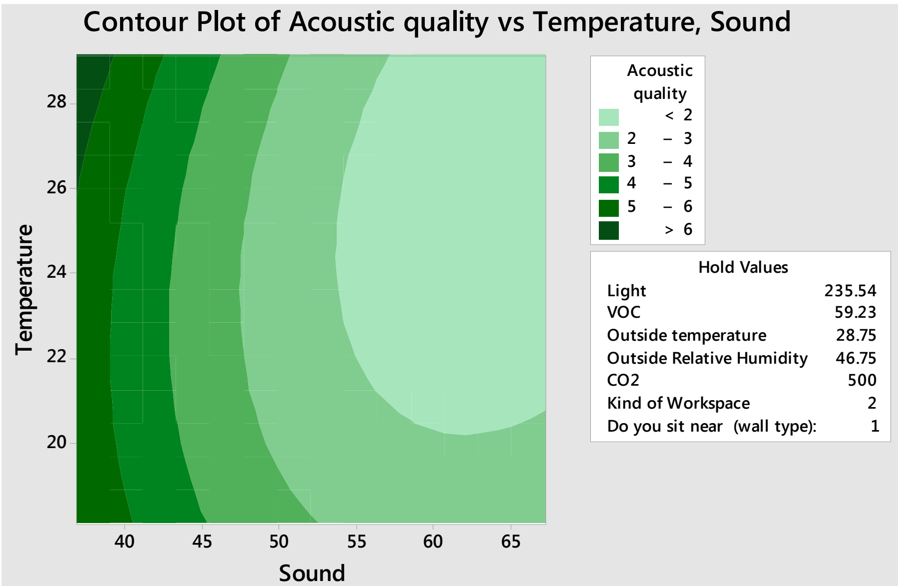


Figure 4.117 - Contour Plot - Effect of Temperature, Sound on Acoustic Comfort

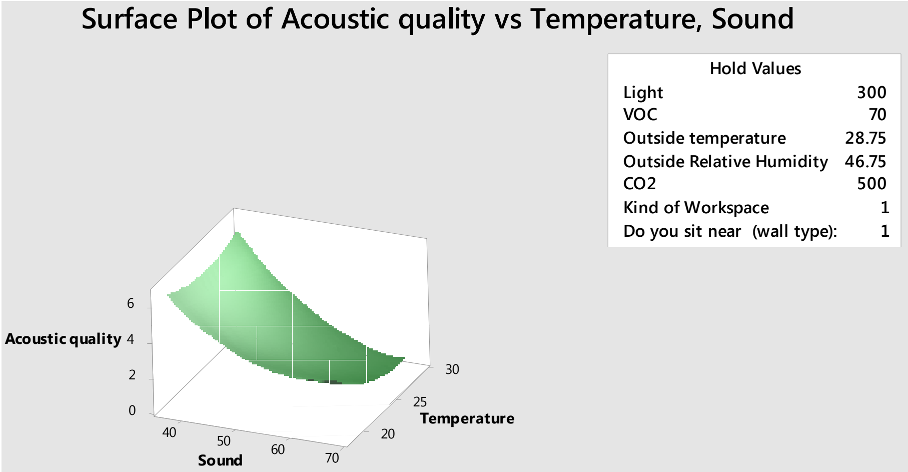


Figure 4.118 - Surface Plot - Effect of Temperature, Sound on Acoustic Comfort

4.6.6.5 Effect of VOC, Sound on Acoustic Comfort and its impact on Productivity

These charts (Figure 4.119, Figure 4.120) show that:

- Both VOC and sound have a significant effect on acoustic comfort and also impact upon productivity. Optimum levels are up to 42dB.
- It is observed that VOC has an indirect influence on acoustic comfort. The plots show that a lower level of VOC gets a negative response from occupants.

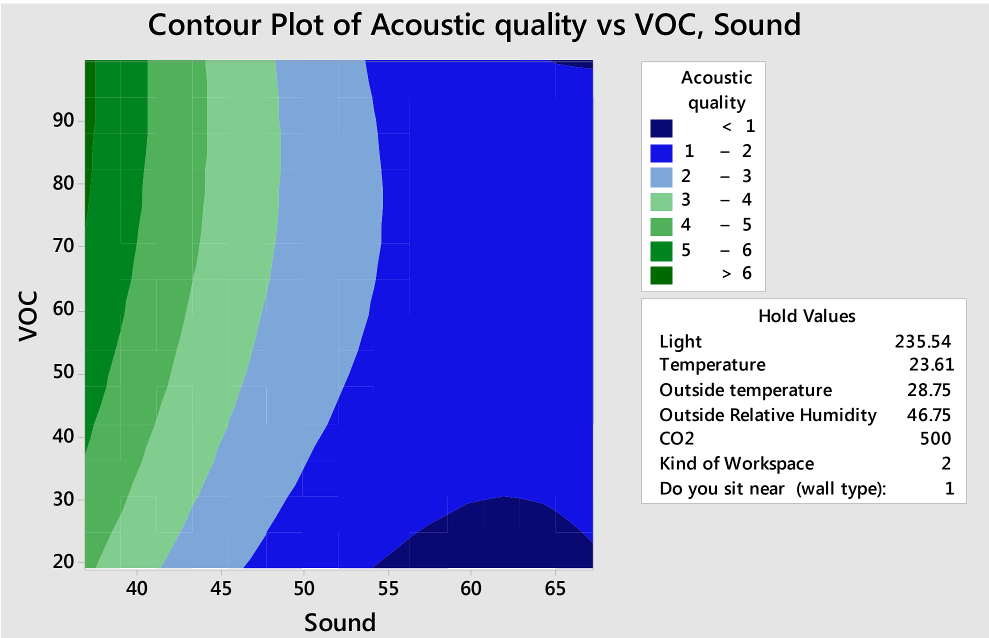


Figure 4.119 - Contour Plot - Effect of VOC, Sound on Acoustic Comfort

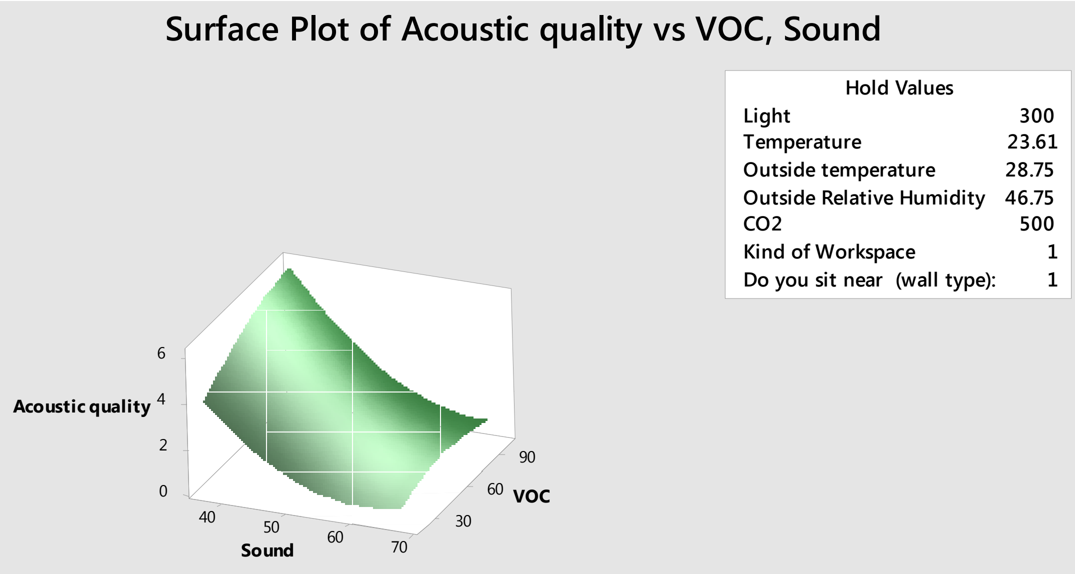


Figure 4.120 - Surface Plot - Effect of VOC, Sound on Acoustic Comfort

4.6.6.6 Effect of Light, Sound on Acoustic Comfort and its impact on Productivity

Below, the contour and surface plots (Figure 4.121, Figure 4.122) outline the following:

- Sound has a significant effect on acoustic comfort and also impacts productivity. Optimum levels are up to 47dB.
- It is observed that light does not have any significant impact on acoustic comfort.

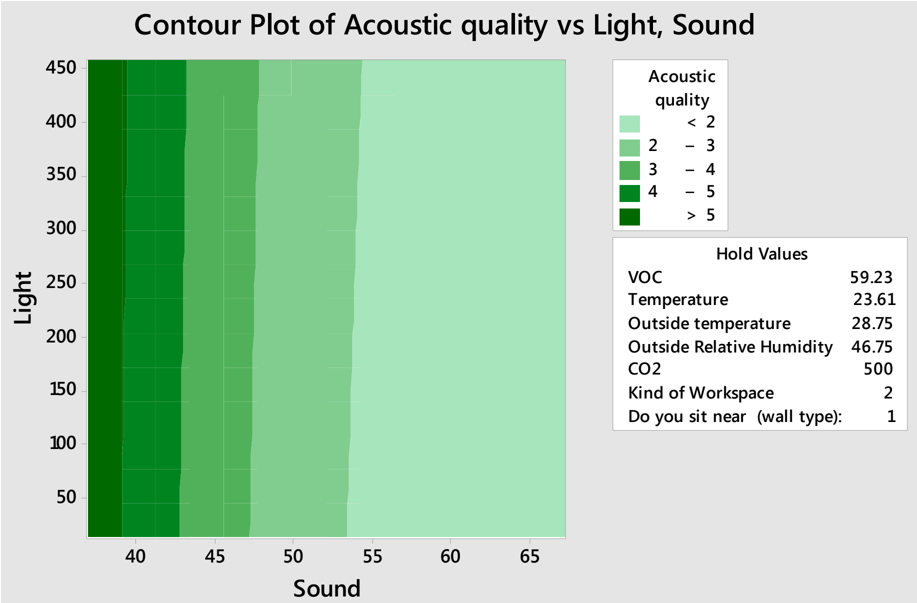


Figure 4.121 - Contour Plot - Effect of Light, Sound on Acoustic Comfort

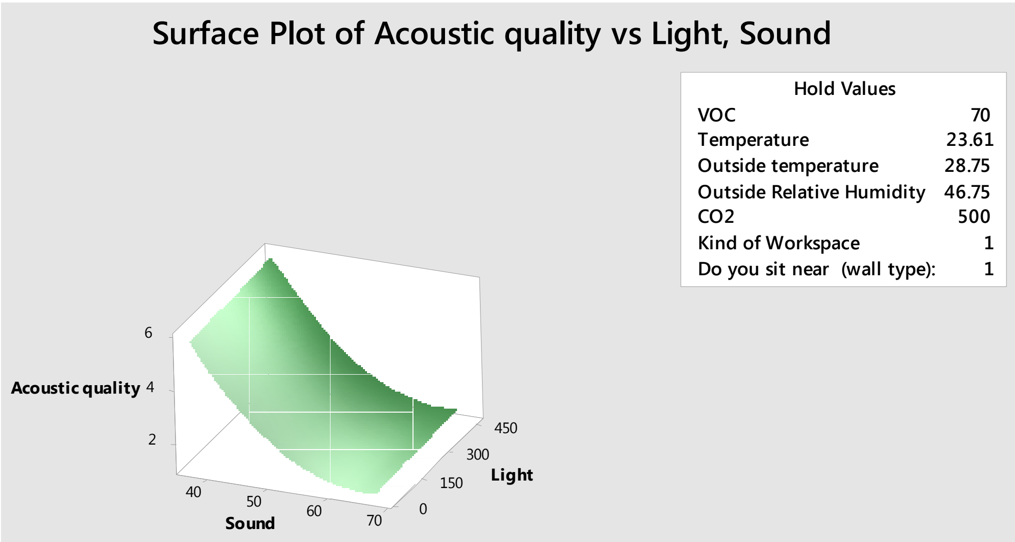


Figure 4.122 - Surface Plot - Effect of Light, Sound on Acoustic Comfort

4.6.7 Summary

This question was aimed to identify the influence of various physical environmental parameters on occupant acoustic comfort levels and how it impacts on productivity.

Primary results of the analysis:

1. It is observed that sound has the most effect on occupant's acoustic comfort and its impact on productivity.
2. Derived regression equation can be used to determine the occupant's acoustic comfort levels in a similar geographic and climatic context.
3. The optimum levels (positive, very positive) of acoustic comfort are observed up to 45 dB and below.
4. Amongst other factors, VOC, temperature and outside relative humidity seem to have an indirect effect on occupant's acoustic comfort and productivity.
5. This analysis also highlights that when occupants are thermally comfortable, they have a greater tendency to identify other discomforts.

4.7 Response Surface Regression for lighting comfort (illumination levels) and Productivity

A response surface analysis of visual comfort was carried out to identify the input variables that influence an occupant's perception of visual comfort and how it affects their productivity. It produced the following:

- P-values for the independent factors their square and 2-way interactions
- R square (coefficient of determination)
- Residual Plots
- Regression equation
- Pareto Chart
- Contour plots
- Surface Plots
- Summary

4.7.1 Analysis of Variance

Source	DF	Adj SS	Adj MS	P-Value
Model	32	398.810	12.463	0.000
Linear	15	339.603	22.640	0.000
Light	1	249.376	249.376	0.000
Temperature	1	2.203	2.203	0.002
Relative Humidity	1	2.196	2.196	0.002
Outside temperature	1	0.048	0.048	0.651
Outside Relative Humidity	1	0.045	0.045	0.661
CO2	1	0.174	0.174	0.387
Sound	1	1.258	1.258	0.020

VOC	1	0.591	0.591	0.111
Kind of Workspace	4	2.408	0.602	0.036
Do you sit near (wall type):	3	1.755	0.585	0.058
Square	3	8.414	2.805	0.000
Light*Light	1	4.312	4.312	0.000
Temperature*Temperature	1	1.493	1.493	0.012
VOC*VOC	1	1.872	1.872	0.005
2-Way Interaction	14	12.064	0.862	0.000
Temperature*CO2	1	1.182	1.182	0.025
Relative Humidity*Outside Relative Humidity	1	2.469	2.469	0.001
Relative Humidity*Kind of Workspace	4	2.344	0.586	0.041
Outside temperature*CO2	1	2.755	2.755	0.001
Outside temperature*VOC	1	2.217	2.217	0.002
Outside temperature*Do you sit near (wall type):	3	2.672	0.891	0.010
Outside Relative Humidity*CO2	1	4.396	4.396	0.000
Outside Relative Humidity*VOC	1	1.553	1.553	0.010
CO2*VOC	1	1.875	1.875	0.005
Error	332	77.042	0.232	
Lack-of-Fit	328	75.542	0.230	
Pure Error	4	1.500	0.375	
Total	364	475.852		

Table 4.6 – Illumination Level (Lighting Comfort)

The experiment was based on the following hypothesis,

- H_0 = Variable has no effect on occupant's visual comfort (artificial light) and its impact on productivity.
- H_{alt} = Variable has an effect on occupant's visual comfort (artificial light) and its impact on productivity.

The ANOVA is done using a=0.1.

If p-value ≥ 0.1, it indicates strong evidence of null hypothesis.

If p-value ≤ 0.1, it indicates strong evidence against the null hypothesis, hence rejecting the null hypothesis.

Based on the ANOVA, the following factors have an effect on occupant visual comfort levels (illumination levels) and its impact on the productivity of occupants (Table 4.6):

1. Light
2. Temperature
3. Relative Humidity
4. Sound
5. Kind of workspace
6. Wall type
7. Light*Light
8. Temperature*Temperature
9. VOC*VOC
10. Temperature*CO^2
11. Relative Humidity*Outside Relative Humidity
12. Relative Humidity *Kind of Workspace

13. Outside Temperature*CO_2

14. Outside Relative Humidity*CO_2

Above factors affect visual comfort both directly and indirectly. All these factors have a different magnitude of influence. The level of magnitude would be highlighted in Pareto charts.

4.7.2 Coefficient of Determination (Multiple correlation coefficient)

The coefficient of determination (adjusted R-square) value is 82.25%. It indicates that 82% of the data fits the regression and there is a significant relationship between dependent and independent variables.

4.7.3 Residual Plots

Residual plots are used to determine the fit of model data (Figure 4.123).

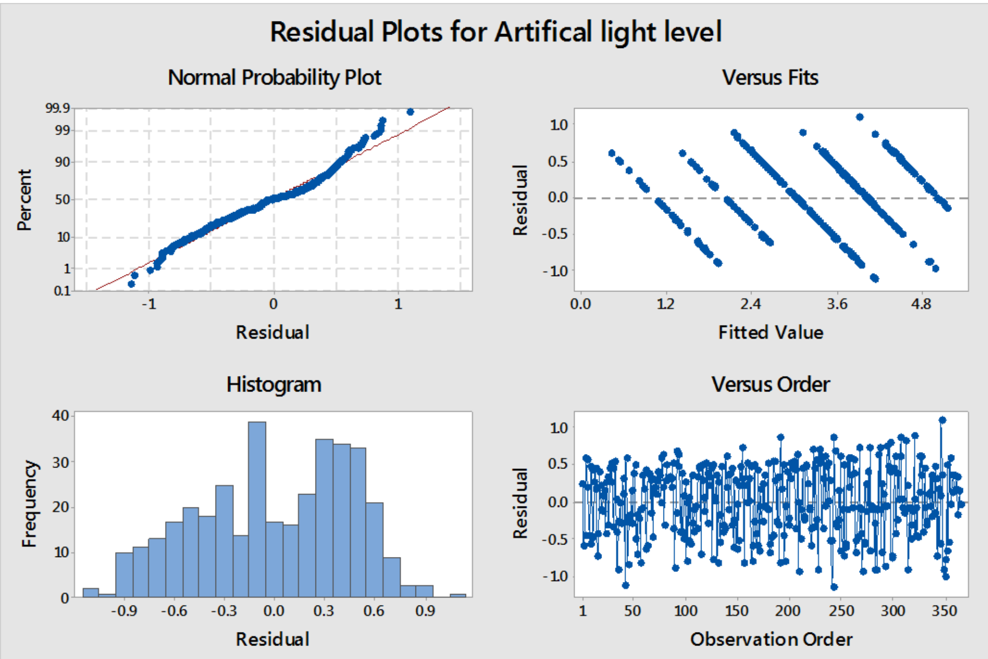


Figure 4.123 – Residual Plots – Artificial Light (Illumination Level)

4.7.3.1 Normal probability plot

The residuals in the figure above follow the expected values (mainline). It indicates that residuals are normally distributed.

4.7.3.2 Versus fits of fitted value plot

The scatter of the residuals varies as the fitted value increases. It indicates that residuals are unequal.

4.7.3.3 Residual Histogram plot

The histogram figure above is observed to be spread over the central area. It is a wide U-shaped histogram with few outliers. It indicates that data is normally distributed.

4.7.3.4 Residual versus order plot

The residuals in the above figure are between -1 to 1 and suggest no pattern. It indicates that regression assumptions are satisfied.

4.7.4 Regression Equation

Artificial light level = -0.42 + 0.01601 Light + 0.580 Temperature - 0.00767 Relative Humidity
- 0.1898 Outside temperature - 0.0960 Outside Relative Humidity
- 0.00173 CO2 + 0.01316 Sound - 0.0064 VOC
+ 0.150 Kind of Workspace_1 + 0.376 Kind of Workspace_2
- 0.659 Kind of Workspace_3 - 0.185 Kind of Workspace_4
+ 0.318 Kind of Workspace_5 - 1.219 Do you sit near (wall type):_1
- 0.023 Do you sit near (wall type):_2
+ 1.183 Do you sit near (wall type):_3
+ 0.058 Do you sit near (wall type):_4 - 0.000012 Light*Light
- 0.01097 Temperature*Temperature - 0.000313 VOC*VOC
- 0.000164 Temperature*CO2
+ 0.000448 Relative Humidity*Outside Relative Humidity
- 0.00338 Relative Humidity*Kind of Workspace_1

- 0.00745 Relative Humidity*Kind of Workspace_2
+ 0.00844 Relative Humidity*Kind of Workspace_3
+ 0.0053 Relative Humidity*Kind of Workspace_4
- 0.00295 Relative Humidity*Kind of Workspace_5
+ 0.000144 Outside temperature*CO2
+ 0.001424 Outside temperature*VOC
+ 0.0348 Outside temperature*Do you sit near (wall type):_1
- 0.00204 Outside temperature*Do you sit near (wall type):_2
- 0.0326 Outside temperature*Do you sit near (wall type):_3
- 0.00024 Outside temperature*Do you sit near (wall type):_4
+ 0.000069 Outside Relative Humidity*CO2
+ 0.000432 Outside Relative Humidity*VOC - 0.000035 CO2*VOC

4.7.4.1 Equation explanation

The regression equation shows various variables that have an effect on occupant's visual comfort and its impact on productivity. This demonstrates that light levels, temperature (both indoor and outdoor) and outside relative humidity influence occupant's visual comfort and its impact on productivity. Along with the factors mentioned above, a few more linear, square and interactions contribute to the final output.

As part of the analysis, various types of graphs are used to show the impact of different input variable on the output variable.

4.7.5 Pareto chart

A Pareto chart is used to present the independent variable's magnitude of effect on the output variable (Figure 4.124). The chart has set 1.65 (standardised effect) as the reference line to identify variables that have an effect on occupant visual comfort and its impact on productivity.

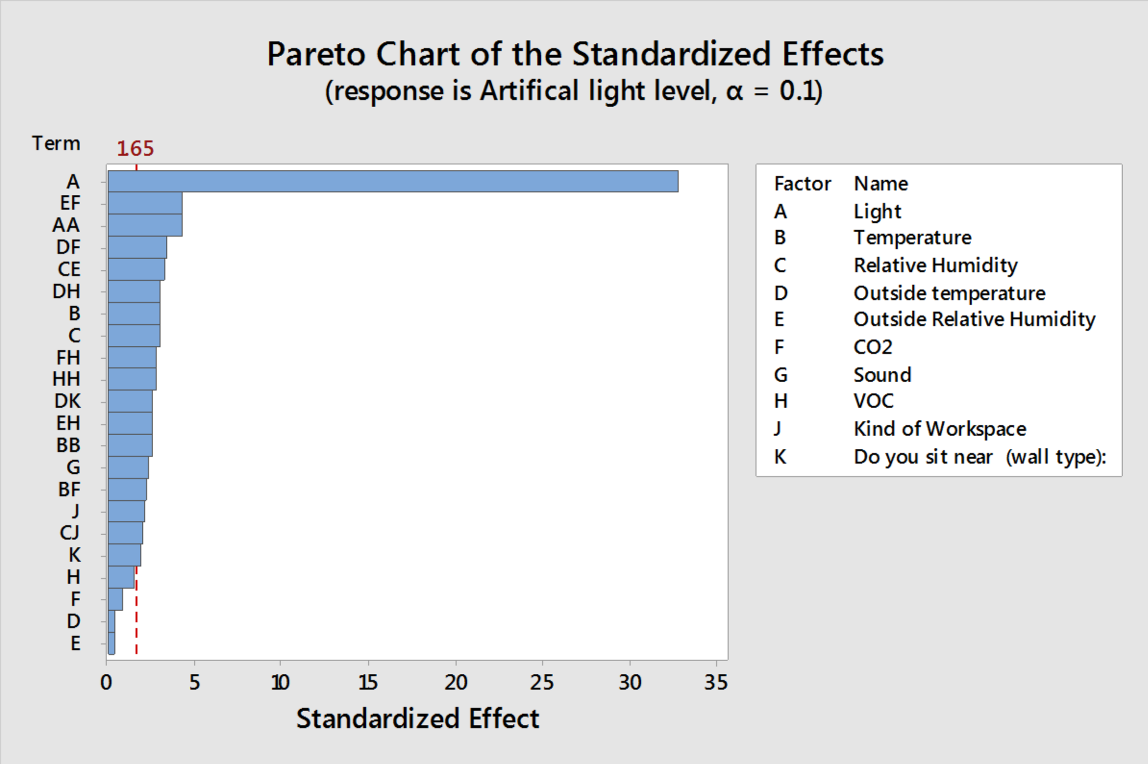


Figure 4.124 – Pareto Chart – Artificial Light

The following variables have a significant effect upon an occupant's visual comfort:

1. Light levels (maximum effect)
2. Outside Relative Humidity*Carbon Dioxide
3. Light*Light
4. Outside Temperature*Carbon Dioxide
5. Relative Humidity*Outside Relative Humidity
6. Outside Temperature*VOC
7. Temperature
8. Relative Humidity
9. CO^2*VOC
10. Temperature*Temperature
11. Sound

4.7.6 Contour and Surface Plots

The contour and surface plot lines are used to identify optimal results by showing the effect of two independent variables on the dependent variable. The researcher has only highlighted the plots that show important impacts or results on visual comfort and its impact on productivity.

4.7.6.1 Effect of Outside Temperature, Outside Relative Humidity on Visual Comfort and its impact on Productivity

Below are contour and surface plot lines (Figure 4.125, Figure 4.126) that outline the following:

- Both outside temperature and outside relative humidity have an effect on occupant visual comfort and productivity
- The higher outside temperature has a positive impact on visual comfort. It indicates that during the daytime, when outside light and temperature is higher, it leads to better Lux levels indoor as well.
- A higher outside relative has a negative effect on light levels.

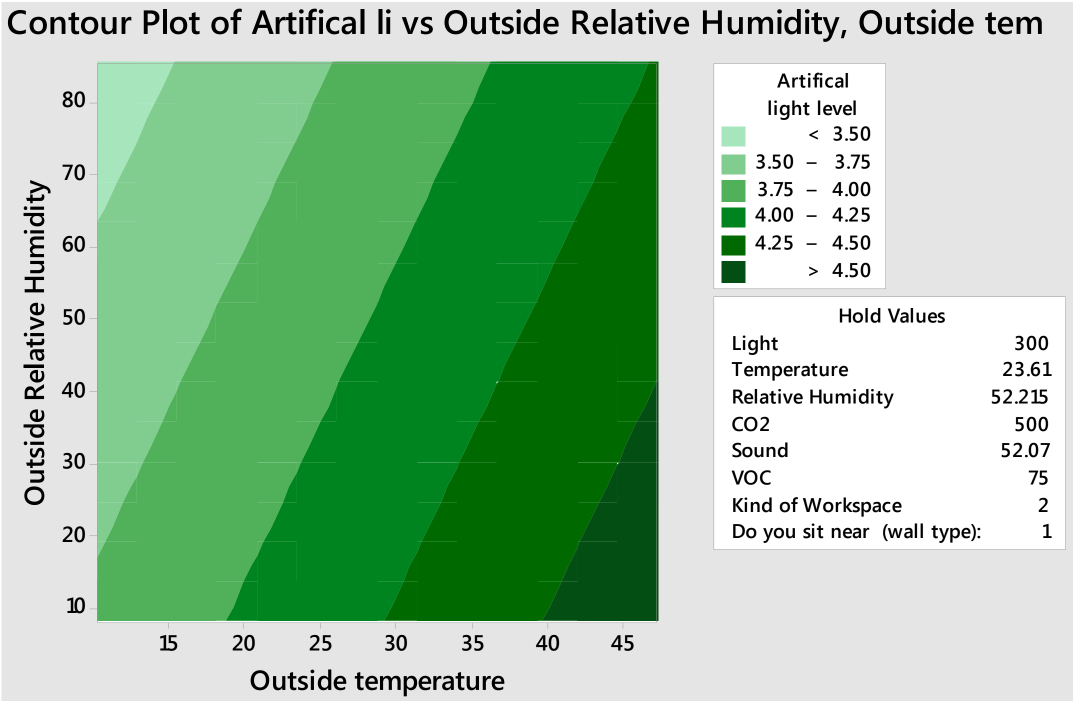


Figure 4.125 – Contour Plot - Effect of Outside Temperature, Outside R.H. on Visual Comfort

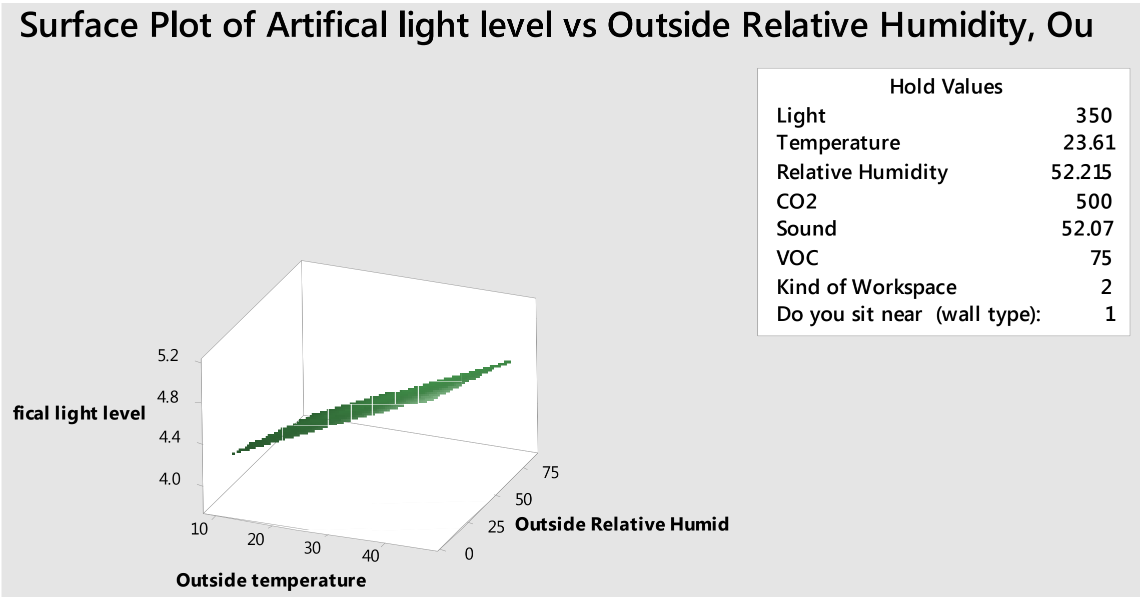


Figure 4.126 - Surface Plot - Effect of Outside Temperature, Outside R.H. on Visual Comfort

4.7.6.2 Effect of Temperature, Carbon Dioxide on Visual Comfort and its impact on Productivity

These contour and surface plots (Figure 4.127, Figure 4.128) show that:

- Temperature and carbon dioxide influence visual comfort and its impact on productivity.
- Temperature range between 20 - 27°c has a very positive influence on visual comfort.
- Carbon dioxide range has a very positive effect when 550 ppm and below.
- The plot lines explain that discussed variables have a direct influence on visual comfort. The comfort window is extensive. Carbon dioxide has neutral comfort up to 1000 ppm, and the temperature is from19-29°c. It indicates that these variables have an indirect effect on visual comfort and productivity.

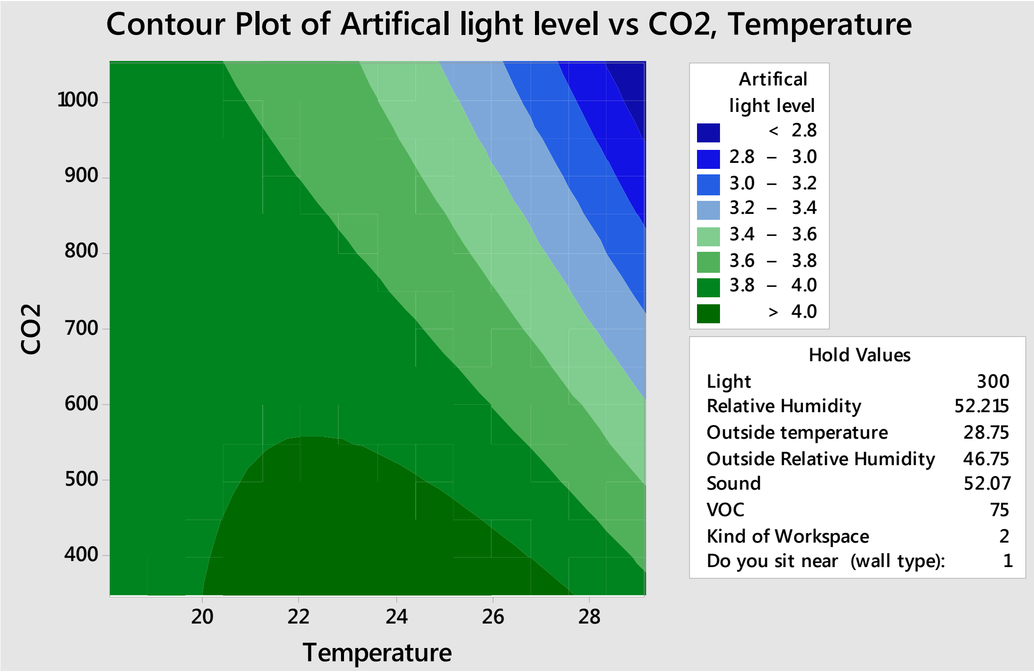


Figure 4.127 - Contour Plot - Effect of Temperature, Carbon Dioxide on Visual Comfort

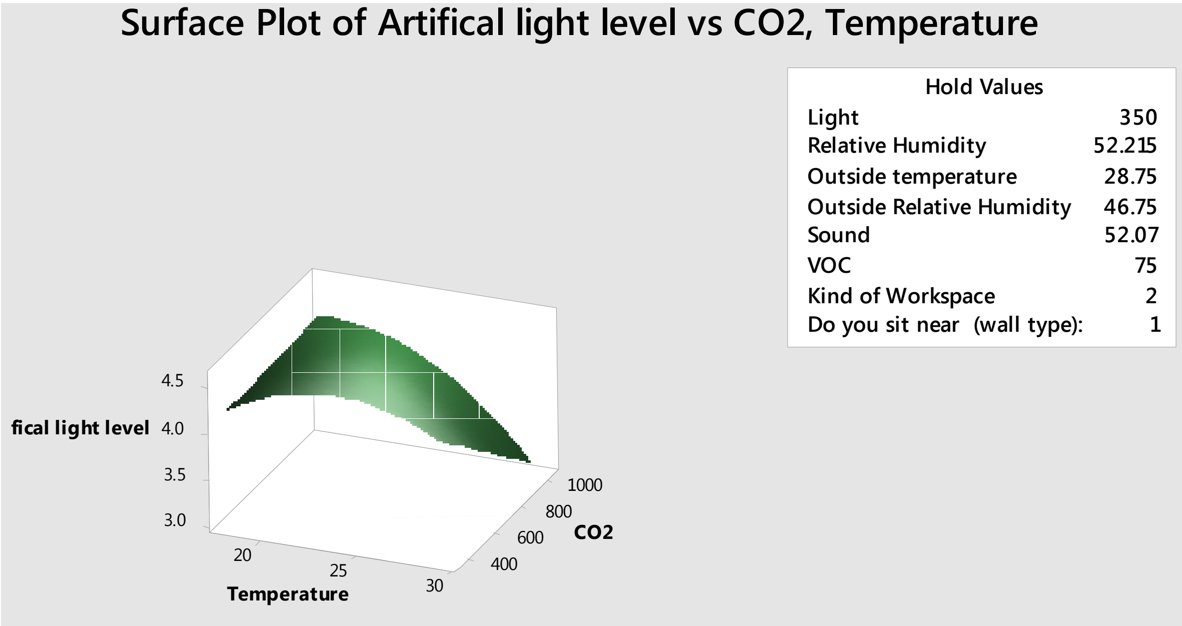


Figure 4.128 - Surface Plot - Effect of Temperature, Carbon Dioxide on Visual Comfort

4.7.6.3 Effect of Temperature, Outside Relative Humidity on Visual Comfort and its impact on Productivity

Below are contour and surface plots (Figure - 4.129, Figure - 4.130) that outline the following:

- Temperature and outside relative humidity influence visual comfort and hence impacts on productivity. It can be noticed that visual comfort decreases as temperature and outside relative humidity increases.
- The optimum range of temperature and outside relative humidity is vast (21- 29°c). It indicates that both these variables have an indirect effect on visual comfort and productivity.

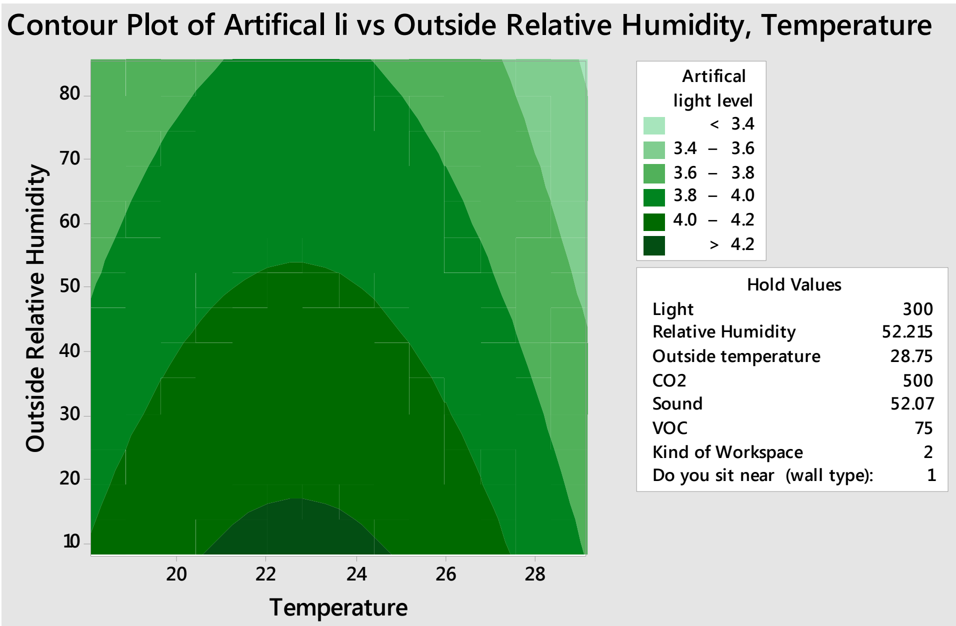


Figure - 4.129 - Contour Plot - Effect of Temperature, Outside R.H. on Visual Comfort

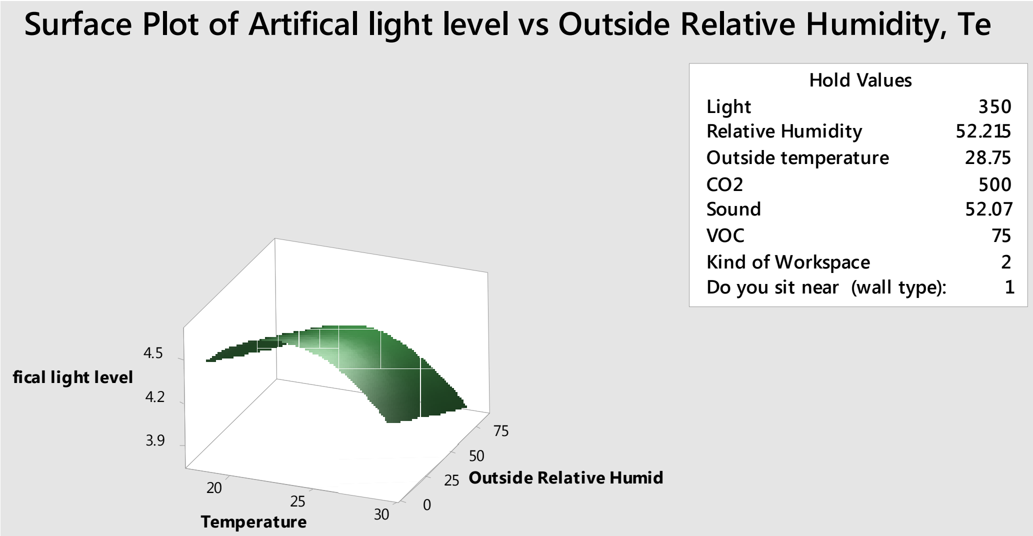


Figure - 4.130 - Surface Plot - Effect of Temperature, Outside R.H. on Visual Comfort

4.7.6.4 Effect of Temperature, Outside Temperature on Visual Comfort and its impact on Productivity

These charts (Figure - 4.131, Figure - 4.132) show that:

- Outside temperature influences visual comfort. Both temperature and daylight are high during the day time in Qatar, which results in improved visual comfort.
- Between the outside temperature and indoor temperature, the indoor temperature has less effect on visual comfort. Plots indicate that the best performance is between 22-24°c.

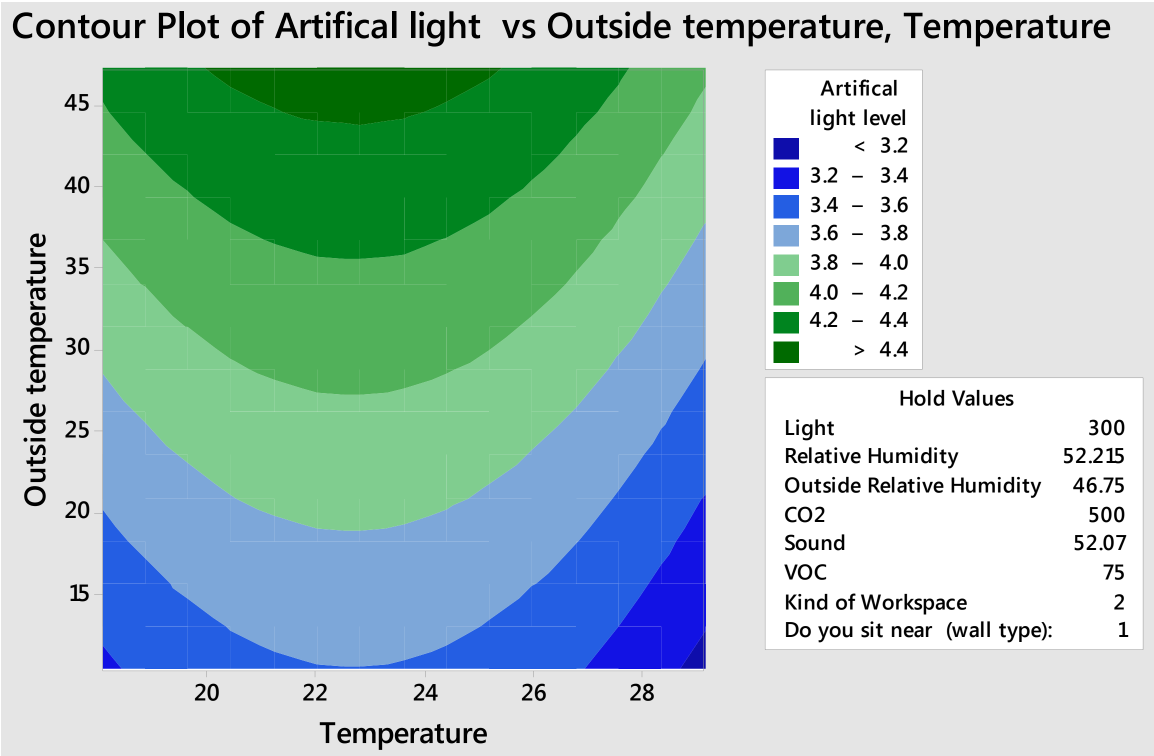


Figure - 4.131 - Contour Plot - Effect of Temperature, Outside Temperature on Visual Comfort

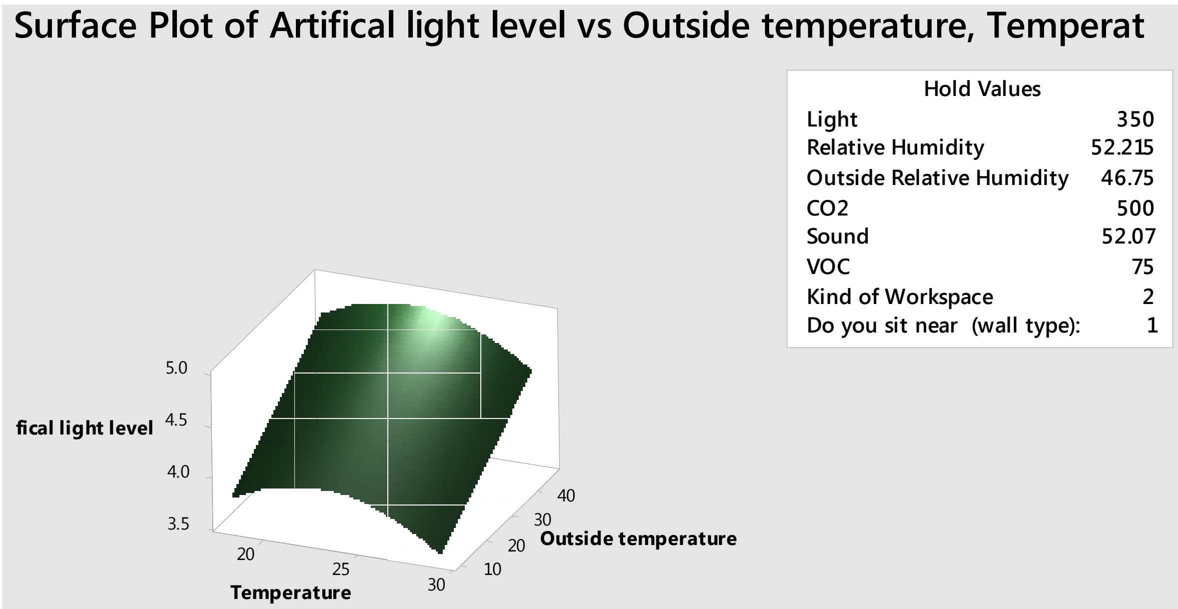


Figure - 4.132- Surface Plot - Effect of Temperature, Outside Temperature on Visual Comfort

4.7.6.5 Effect of VOC, Light on Visual Comfort and its impact on Productivity

Below are contour and surface plot lines (Figure - 4.133, Figure - 4.134) that reveal the following:

- VOC does not show any effect on visual comfort.
- Light levels have a significant impact on visual comfort. The plot indicates that lighting level has a significant impact on visual comfort. The optimum lighting levels are 350-450 Lux.

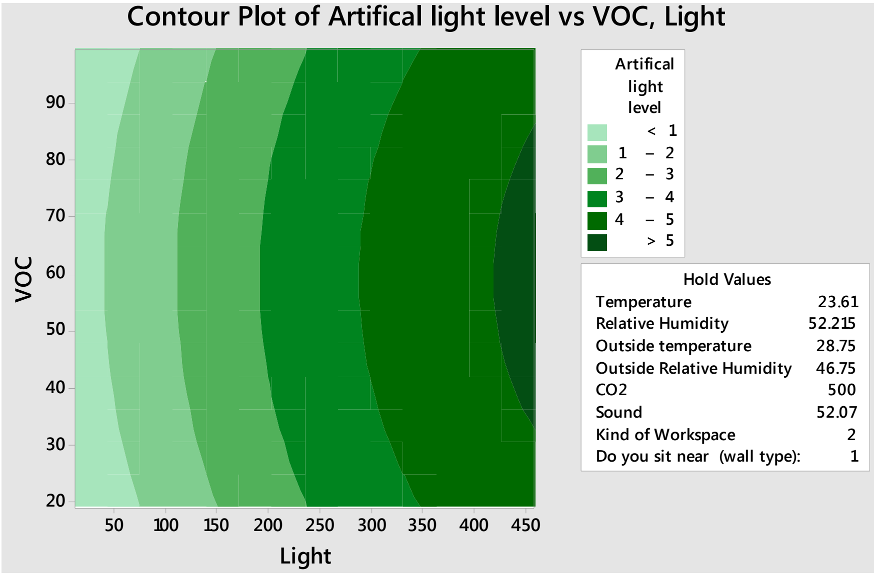


Figure - 4.133 - Contour Plot - Effect of VOC, Light on Visual Comfort

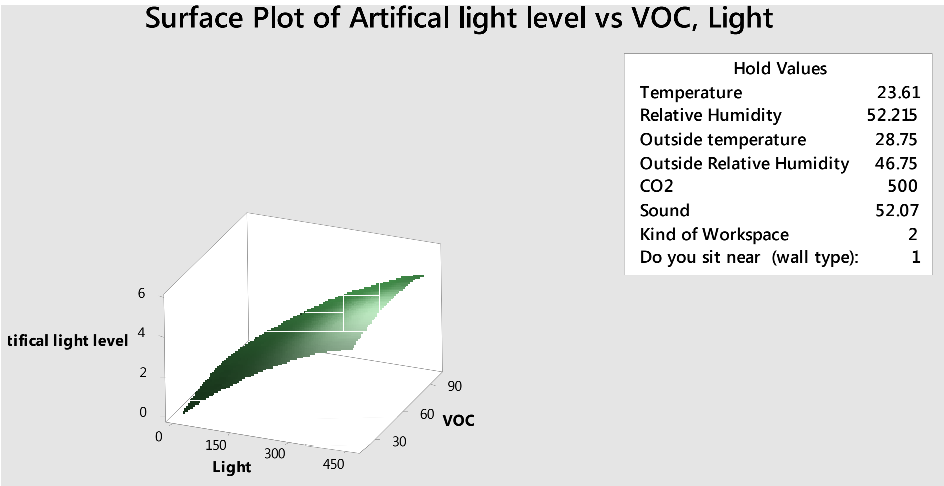


Figure - 4.134 -Surface Plot - Effect of VOC, Light on Visual Comfort

4.7.6.6 Effect of Sound, Light on Visual Comfort and its impact on Productivity

These charts (Figure - 4.135, Figure - 4.136) show the following:

- The plot lines indicate that sound does not have a significant effect on visual comfort.
- Lighting levels have a direct effect on visual comfort, and the optimum range is 325 - 450 Lux.

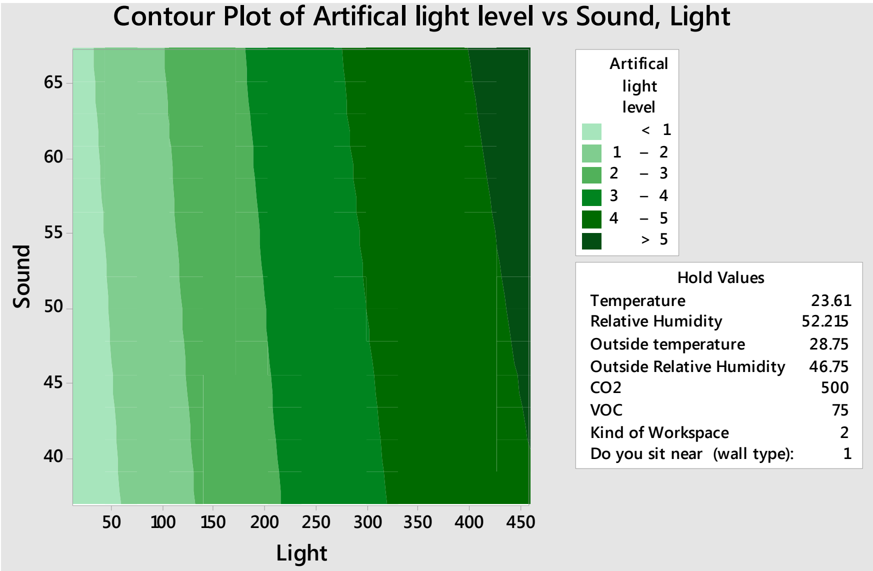


Figure - 4.135 - Contour Plot - Effect of Sound, Light on Visual Comfort

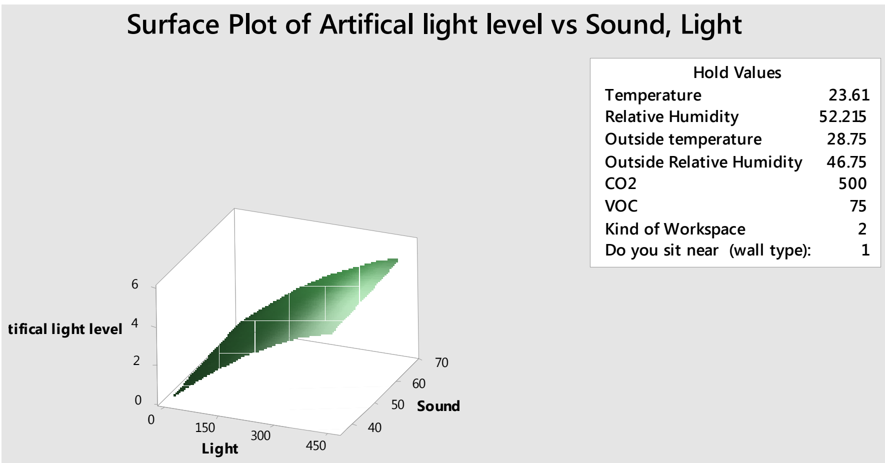


Figure - 4.136 - Surface Plot - Effect of Sound, Light on Visual Comfort

4.7.6.7 Effect of Outside Relative Humidity, Light on Visual Comfort and its impact on Productivity

These contour and surface plots (Figure - 4.137, Figure - 4.138) outline the following:

- Outside relative humidity does not have a significant effect on visual comfort.
- Light levels have a direct effect on visual comfort, and the optimum range is 275 - 450 Lux.

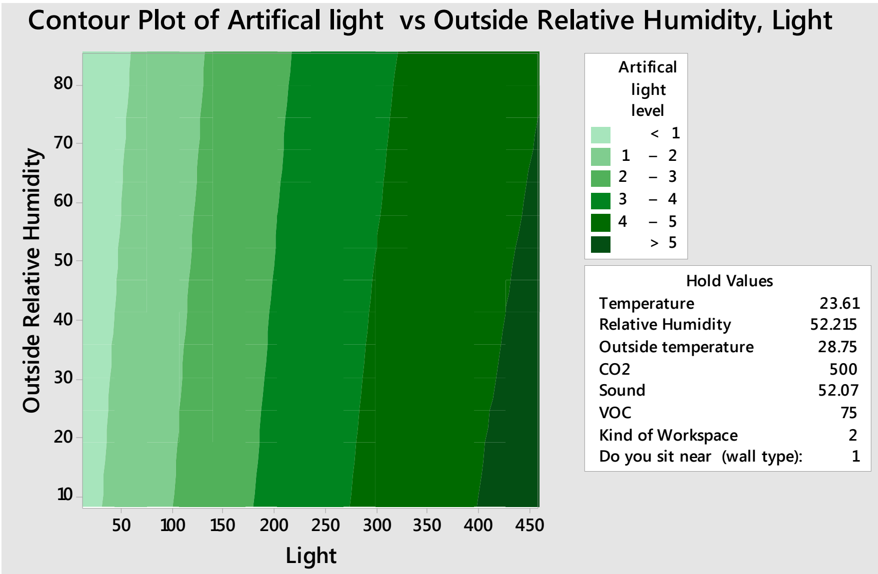


Figure - 4.137 - Contour Plot - Effect of Outside R.H., Light on Visual Comfort

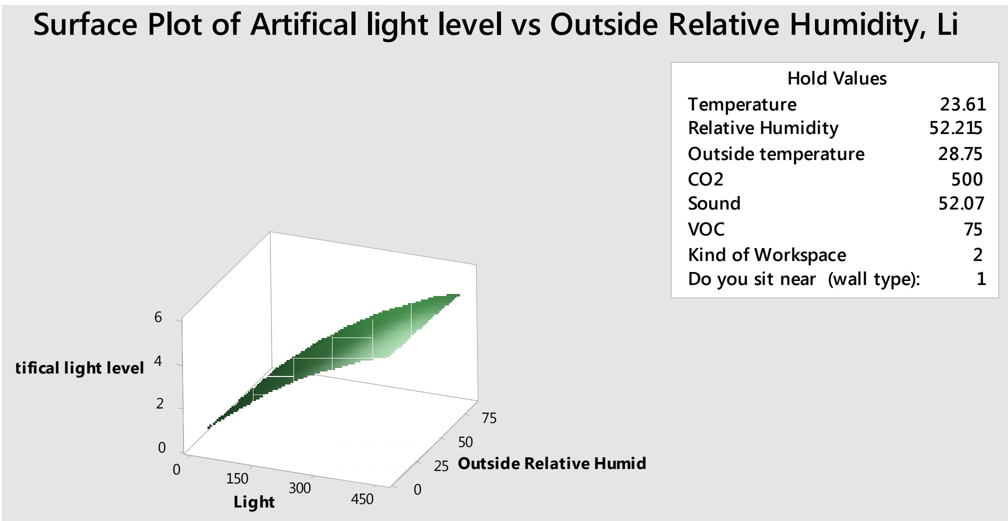


Figure - 4.138 - Surface Plot - Effect of Outside R.H., Light on Visual Comfort

4.7.6.8 Effect of Outside Temperature, Light on Visual Comfort and its impact on Productivity

These contour and surface plots (Figure - 4.139, Figure - 4.140) show that:

- Outside temperature does not have a significant effect on visual comfort.
- Light levels have a direct effect on visual comfort, and optimum range is 350 - 450 Lux.

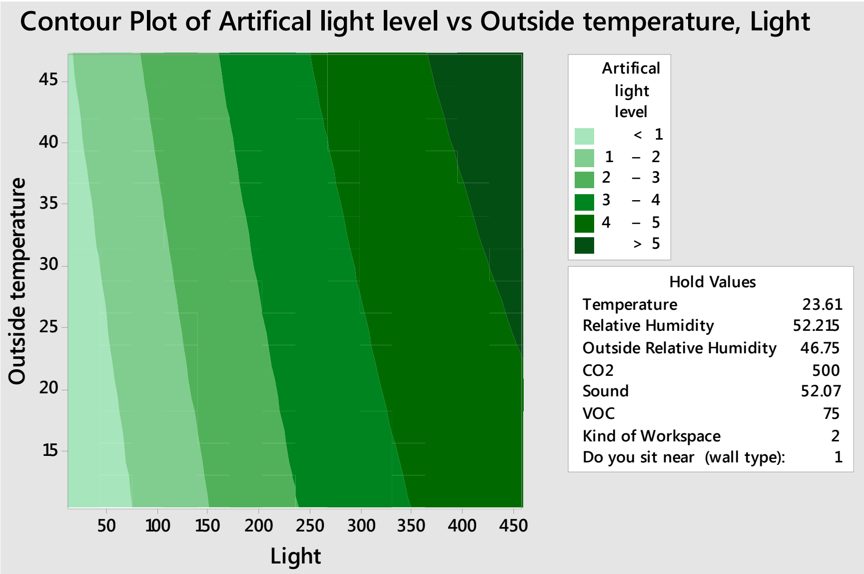


Figure - 4.139 – Contour Plot - Effect of Outside Temperature, Light on Visual Comfort

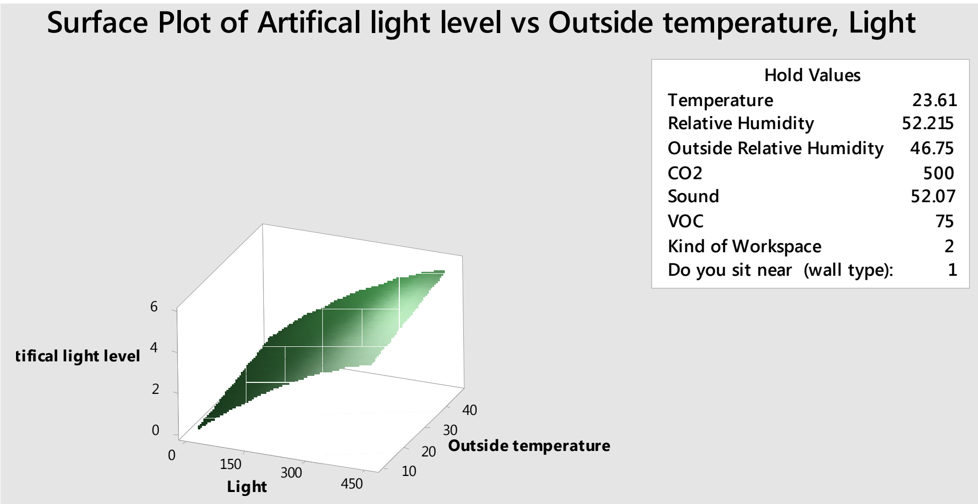


Figure - 4.140- Surface Plot - Effect of Outside Temperature, Light on Visual Comfort

4.7.6.9 Effect of Relative Humidity, Light on Visual Comfort and its impact on Productivity

These charts outline the following:

- Relative humidity does not have a significant effect on visual comfort.
- Light levels have a direct effect on visual comfort, and optimum range is 325 - 450 Lux.

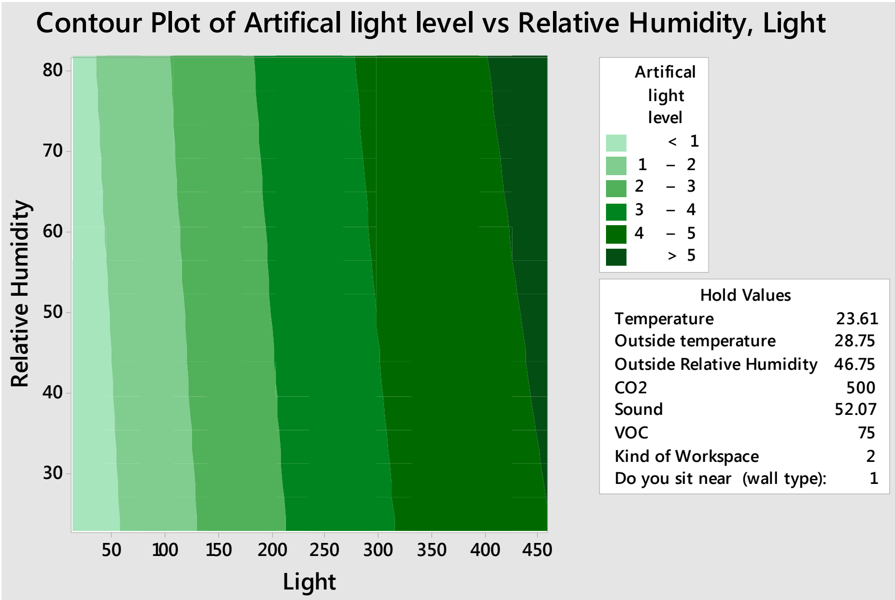


Figure - 4.141 - Contour Plot - Effect of Relative Humidity, Light on Visual Comfort

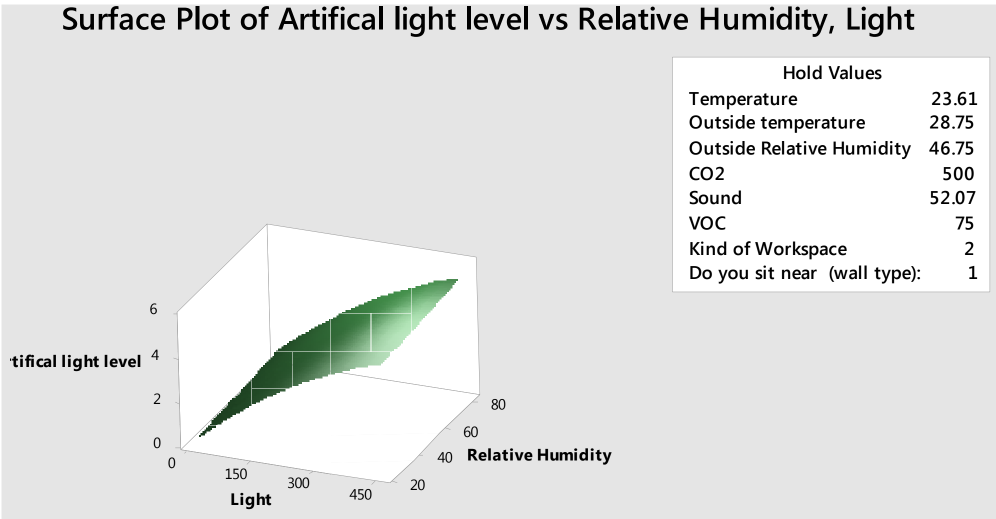


Figure - 4.142 - Surface Plot - Effect of Relative Humidity, Light on Visual Comfort

4.7.6.10 Effect of Relative Humidity, Light on Visual Comfort and its impact on Productivity

The contour and surface plots, below, (Figure - 4.143Figure - 4.144) outline the following:

- Temperature does not have a significant effect on visual comfort.
- Light levels have a direct effect on visual comfort, and optimum range is 325 - 450 Lux.

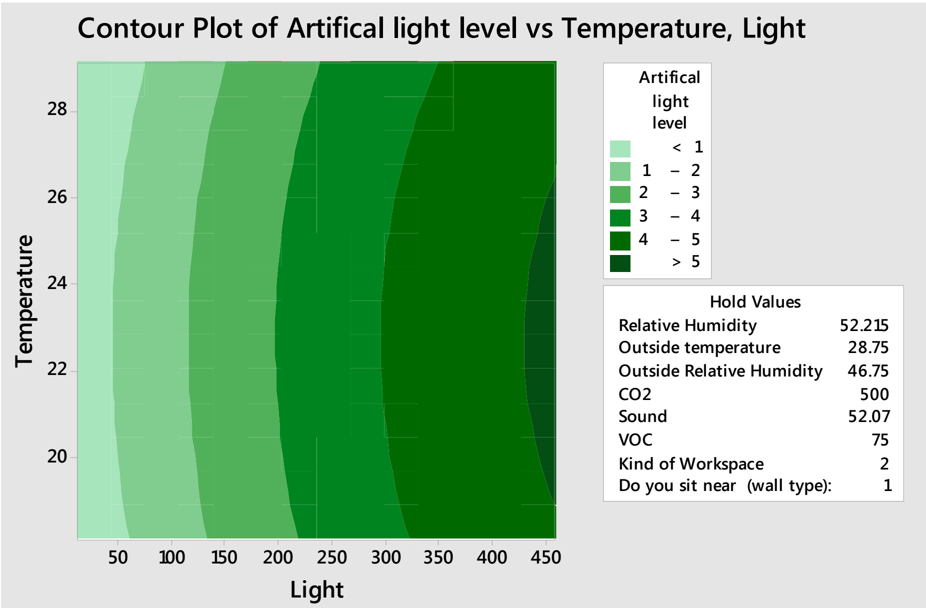


Figure - 4.143 – Contour Plot - Effect of Relative Humidity, Light on Visual Comfort

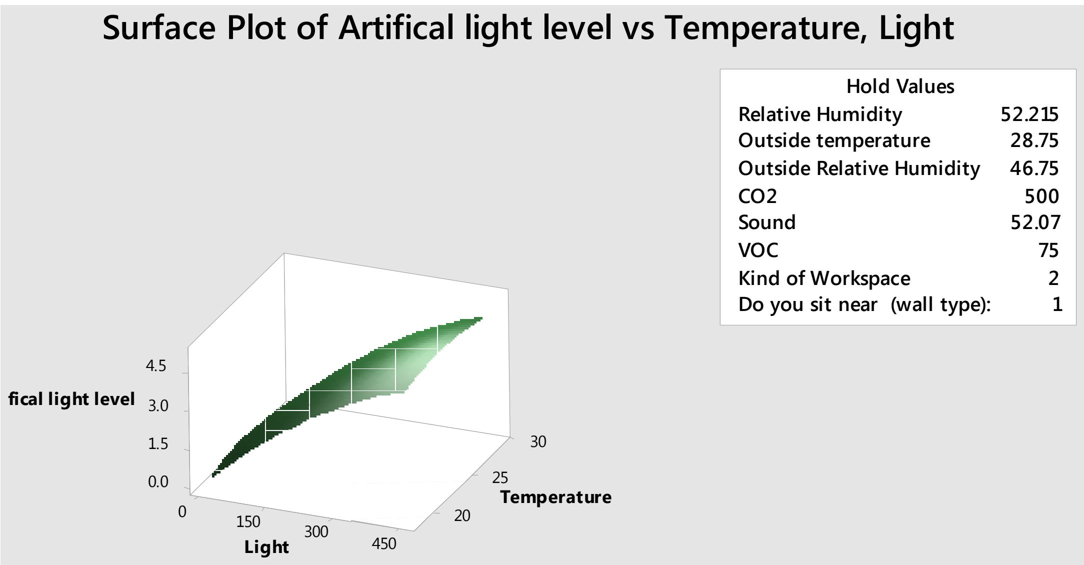


Figure - 4.144 - Surface Plot - Effect of Relative Humidity, Light on Visual Comfort

4.7.7 <u>Summary</u>

This question was aimed at identifying the influence of various physical environmental parameters on occupant visual comfort and their impact on productivity.

Here are the primary results of the analysis:

1. It is observed that the lux level has a maximum effect on occupant visual comfort and impact positively on productivity.
2. A derived regression equation can be used to determine the occupant visual comfort in a similar geographic and climatic context.
3. The optimum level of light (positive, very positive) for visual comfort is from 300 - 450 Lux.
4. Amongst other factors, higher outside temperature also has a positive correlation with visual comfort. During the daytime, the temperature is higher due to sunlight. It also contributes to higher daylight levels, which can affect indoor illumination.

4.8 Response Surface Regression for Visual Comfort (Natural Light) and Productivity

A response surface analysis of visual comfort was done to identify the input variables that influence occupant visual comfort (natural light) and its impact on their productivity. This question was focused on natural light within visual comfort.

- P-values for the independent factors their square and 2-way interactions
- R-square (coefficient of determination)
- Residual Plots
- Regression equation
- Pareto Chart
- Summary

4.8.1 Analysis of Variance

Source	DF	Adj SS	Adj MS	P-Value
Model	25	887.938	35.518	0.000
Linear	12	696.147	58.012	0.000
Light	1	0.289	0.289	0.090
Temperature	1	0.179	0.179	0.181
Relative Humidity	1	0.134	0.134	0.247
Outside temperature	1	0.488	0.488	0.028

Outside Relative Humidity	1	0.001	0.001	0.907
Kind of Workspace	4	0.197	0.049	0.741
Do you sit near (wall type):	3	564.186	188.062	0.000
Square	2	1.772	0.886	0.000
Temperature*Temperature	1	0.331	0.331	0.069
Outside Relative Humidity*Outside Relative Humidity	1	1.418	1.418	0.000
2-Way Interaction	11	4.278	0.389	0.000
Light*Do you sit near (wall type):	3	0.917	0.306	0.028
Temperature*Kind of Workspace	4	1.068	0.267	0.032
Relative Humidity*Do you sit near (wall type):	3	0.884	0.295	0.033
Outside temperature*Outside Relative Humidity	1	1.053	1.053	0.001
Error	339	33.799	0.100	
Lack-of-Fit	335	33.299	0.099	0.713
Pure Error	4	0.500	0.125	
Total	364	921.7		

Table - 4.7 – Analysis of Variance – Natural Light – Visual Comfort

The experiment was based on the following hypothesis,

- H_0 = Variable has no effect on occupant's visual comfort (natural light) and its impact on productivity.
- H_{alt} = Variable has an effect on occupant's visual comfort (natural light) and its impact on productivity.

The ANOVA is done using a=0.1.

If p-value ≥ 0.1, it indicates strong evidence of null hypothesis.

If p-value ≤ 0.1, it indicates strong evidence against the null hypothesis, hence rejecting the null hypothesis.

Based on the ANOVA, the following factors have an effect on occupant's visual comfort (natural light) and its impact on the productivity of occupants (Table - 4.7):

1. Light
2. Outside Temperature
3. Wall type
4. Temperature*Temperature
5. Outside Relative Humidity*Outside Relative Humidity
6. Light*Wall type
7. Temperature*Kind of Workspace
8. Relative Humidity*Wall type
9. Outside Temperature*Outside Relative Humidity

The above factors affect visual comfort both directly and indirectly. All these factors have a different magnitude of influence. The level of magnitude would be highlighted in Pareto charts.

4.8.2 The Coefficient of Determination (Multiple Correlation Coefficient)

The coefficient of determination (Adjusted R-square) value is 96.06%. It indicates that 96% of the data fits the regression and there is a significant relationship between dependent and independent variables.

4.8.3 Residual Plots

Residual plots are used to determine the fit of model data (Figure - 4.145).

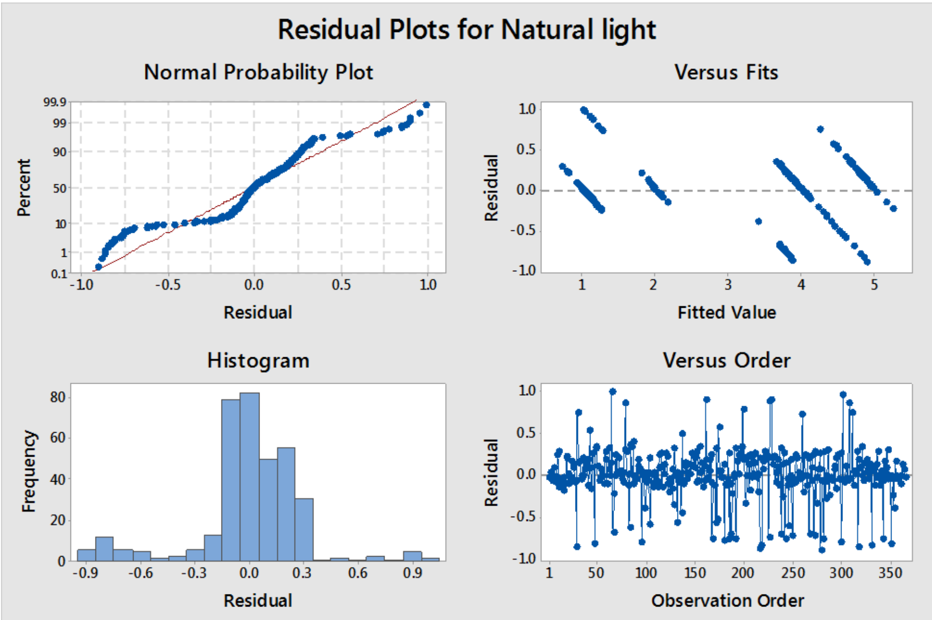


Figure - 4.145 – Residual Plots – Natural Light

4.8.3.1 Normal probability

The residuals in the above figure above follow the expected values (mainline). This indicates that the residuals are normally distributed.

4.8.3.2 Versus fits of the fitted value

The scatter of the residuals varies as the fitted value increases. It indicates that the residuals are unequal.

4.8.3.3 Residual Histogram

The histogram figure above is observed to be spread over the central area. It is a U-shaped histogram with few outliers. It indicates that data is normally distributed.

4.8.3.4 Residual versus order plot

The residuals in the above figure are between -1 to 1 and suggest no pattern. It indicates that regression assumptions are satisfied.

4.8.4 Regression Equation

Natural light = 7.66 - 0.000514 Light - 0.253 Temperature - 0.00286 Relative Humidity
- 0.0259 Outside temperature - 0.0507 Outside Relative Humidity
- 1.086 Kind of Workspace_1 - 0.844 Kind of Workspace_2
- 0.531 Kind of Workspace_3 + 0.120 Kind of Workspace_4
+ 2.340 Kind of Workspace_5 - 0.856 Do you sit near (wall type):_1
- 2.220 Do you sit near (wall type):_2
+ 2.415 Do you sit near (wall type):_3
+ 0.662 Do you sit near (wall type):_4 + 0.00496 Temperature*Temperature
+ 0.000308 Outside Relative Humidity*Outside Relative Humidity
- 0.000015 Light*Do you sit near (wall type):_1
+ 0.000412 Light*Do you sit near (wall type):_2
- 0.001110 Light*Do you sit near (wall type):_3
+ 0.000713 Light*Do you sit near (wall type):_4
+ 0.0430 Temperature*Kind of Workspace_1
+ 0.0377 Temperature*Kind of Workspace_2
+ 0.0237 Temperature*Kind of Workspace_3
- 0.0056 Temperature*Kind of Workspace_4
- 0.0988 Temperature*Kind of Workspace_5
- 0.00002 Relative Humidity*Do you sit near (wall type):_1
+ 0.00539 Relative Humidity*Do you sit near (wall type):_2
- 0.00676 Relative Humidity*Do you sit near (wall type):_3
+ 0.00139 Relative Humidity*Do you sit near (wall type):_4
+ 0.000771 Outside temperature*Outside Relative Humidity

4.8.4.1 Equation explanation

The regression equation shows various variables that have an effect on occupant visual comfort (natural light) and its impact on productivity. It shows that light levels, temperature, wall type and outside temperature have an influence on an occupant's visual comfort (need for natural light) and its impact on productivity. Along with the factors mentioned above, more linear, square and interactions contribute to the final output.

As part of the analysis, various types of graphs are used to show the impact of different input variable on the output variable.

4.8.5 Pareto Chart

A Pareto chart has been used to present the independent variable's magnitude of effect on the output variable (Figure - 4.146). The chart has set 1.65 (standardised effect), as the reference line to identify variables that have an effect on occupant visual comfort (natural light) and its impact on productivity.

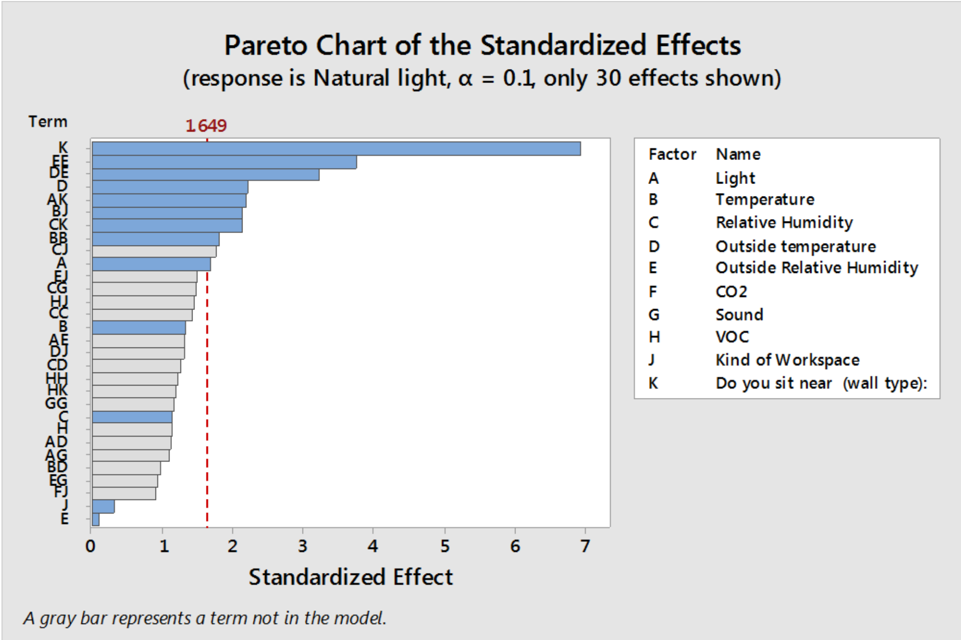


Figure - 4.146 - Pareto Chart - Natural Light

The following variables have a significant effect (direct and indirect) on an occupant's visual comfort (natural light):

1. Wall type (maximum effect)
2. Outside Relative Humidity*Outside Relative Humidity
3. Outside Temperature*Outside Relative Humidity
4. Outside Temperature
5. Light*Wall type
6. Temperature*Kind of Workspace
7. Relative Humidity*Wall type
8. Temperature*Temperature

4.8.6 Main Effects Graph

The response surface analysis did not produce any relevant contour and surface plots in this analysis.

The main effects have been plotted on the graph, below, to show the impact of natural light on occupant productivity, (Figure - 4.147). It outlines that amongst all the variables, only the wall type (natural light) has a significant effect on visual comfort and its impact on productivity. It shows that the ingress of natural light to the occupant's seat has an effect on their productivity.

The occupant's response can be explained:

- Wall type (1) – Exterior wall – It shows that occupants seated near an external wall have responded negative impact of natural light. This is due to the absence of natural light.
- Wall type (2) – Interior wall - It is similar to the exterior wall. No access to natural light has led to negative effect on visual comfort and impacts productivity.
- Wall type (3) – Exterior window – Occupants seated near the exterior windows responded with a significant amount of positive visual comfort due to the ingress of natural light and results in increased productivity.
- Wall type (4) – Interior Window – Occupants seated near the interior window responded with positive responses. It indicates that a central window opening into the common spaces and atriums also have a positive effect on occupant visual comfort and productivity.

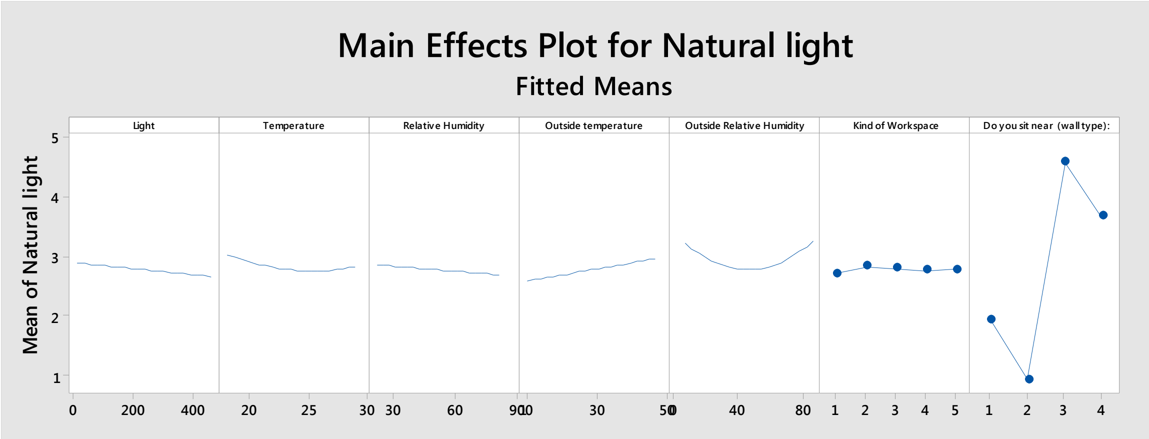


Figure - 4.147 – Main Effects Plot – Natural Plot

4.9 Response Surface Regression for Office Layout and its Effect on Comfort and Productivity

The response surface analysis for an office layout was completed to investigate whether office layout influences occupant comfort and productivity. The analysis produced the following:

- P-values for the independent factors their square and 2-way interactions
- R square (coefficient of determination)
- Residual Plots
- Regression equation
- Pareto Chart
- Summary

4.9.1 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	61	345.058	5.6567	8.10	0.000
Linear	15	49.123	3.2748	4.69	0.000
Temperature	1	2.646	2.6461	3.79	0.053
Relative Humidity	1	0.000	0.0002	0.00	0.988
Outside temperature	1	4.199	4.1993	6.01	0.015
Outside Relative Humidity	1	1.624	1.6239	2.32	0.128
CO2	1	0.813	0.8132	1.16	0.282
Sound	1	1.561	1.5613	2.23	0.136
Light	1	0.592	0.5921	0.85	0.358
VOC	1	0.331	0.3313	0.47	0.492
Kind of Workspace	4	34.269	8.5672	12.26	0.000
Do you sit near (wall type):	3	5.952	1.9841	2.84	0.038
Square	4	17.348	4.3370	6.21	0.000

Outside temperature*Outside temperature	1	9.946	9.9455	14.23	0.000
Outside Relative Humidity*Outside Relative Humidity	1	3.481	3.4809	4.98	0.026
CO2*CO2	1	5.177	5.1765	7.41	0.007
Light*Light	1	4.614	4.6140	6.60	0.011
2-Way Interaction	42	118.716	2.8266	4.05	0.000
Temperature*CO2	1	2.410	2.4100	3.45	0.064
Temperature*Sound	1	19.462	19.462	27.85	0.000
Temperature*Do you sit near (wall type):	3	5.914	1.9714	2.82	0.039
Relative Humidity*CO2	1	3.274	3.2739	4.69	0.031
Relative Humidity*VOC	1	4.969	4.9694	7.11	0.008
Outside temperature*Outside Relative Humidity	1	5.933	5.9330	8.49	0.004
Outside temperature*Sound	1	9.589	9.5895	13.72	0.000
Outside temperature*Kind of Workspace	4	6.808	1.7021	2.44	0.047
Outside temperature*Do you sit near (wall type):	3	7.616	2.5386	3.63	0.013
Outside Relative Humidity*Do you sit near (wall type):	3	8.575	2.8582	4.09	0.007
CO2*Sound	1	3.625	3.6251	5.19	0.023
CO2*Kind of Workspace	4	8.482	2.1206	3.04	0.018
Sound*Kind of Workspace	4	13.130	3.2826	4.70	0.001
Sound*Do you sit near (wall type):	3	16.352	5.4507	7.80	0.000
Light*Kind of Workspace	4	18.280	4.5701	6.54	0.000
VOC*Kind of Workspace	4	5.618	1.4045	2.01	0.093
VOC*Do you sit near (wall type):	3	6.610	2.2032	3.15	0.025
Error	303	211.709	0.6987		
Lack-of-Fit	299	209.209	0.6997	1.12	0.532
Pure Error	4	2.500	0.6250		
Total	364	556.767			

Table 4.8 – Analysis of Variance – Office Layout

The experiment was based on the following hypothesis,

- H_0 = Variable has no effect on the occupant's comfort (office layout) and productivity.
- H_{alt} = Variable has an effect on occupant's visual comfort (office layout) and productivity.

The ANOVA is done using a=0.1.

If p-value ≥ 0.1, it indicates strong evidence of null hypothesis.

If p-value ≤ 0.1, it indicates strong evidence against the null hypothesis, hence rejecting the null hypothesis.

Based on the ANOVA, the following factors have an effect on occupant's comfort (office layout) and productivity of occupants (Table 4.8):

1. Temperature
2. Outside temperature
3. Kind of Workspace
4. Do you sit near (wall type)
5. Outside temperature*Outside temperature
6. Outside relative humidity*Outside relative humidity
7. CO^2*CO^2
8. Light*Light
9. Temperature*CO^2
10. Temperature*Sound
11. Temperature*Do you sit near (wall type)

Above factors affect comfort both directly and indirectly. All these factors have a different magnitude of influence. The level of magnitude would be highlighted in Pareto charts.

4.9.2 Co-Efficient of Determination (Multiple Correlation Coefficient)

The coefficient of determination (adjusted R-square) value is 67.66%. It indicates that 68% of the data fits the regression and there is a significant relationship between dependent and independent variables.

4.9.3 Residual Plots

Residual plots are used to determine the fit of model data (Figure 4.148).

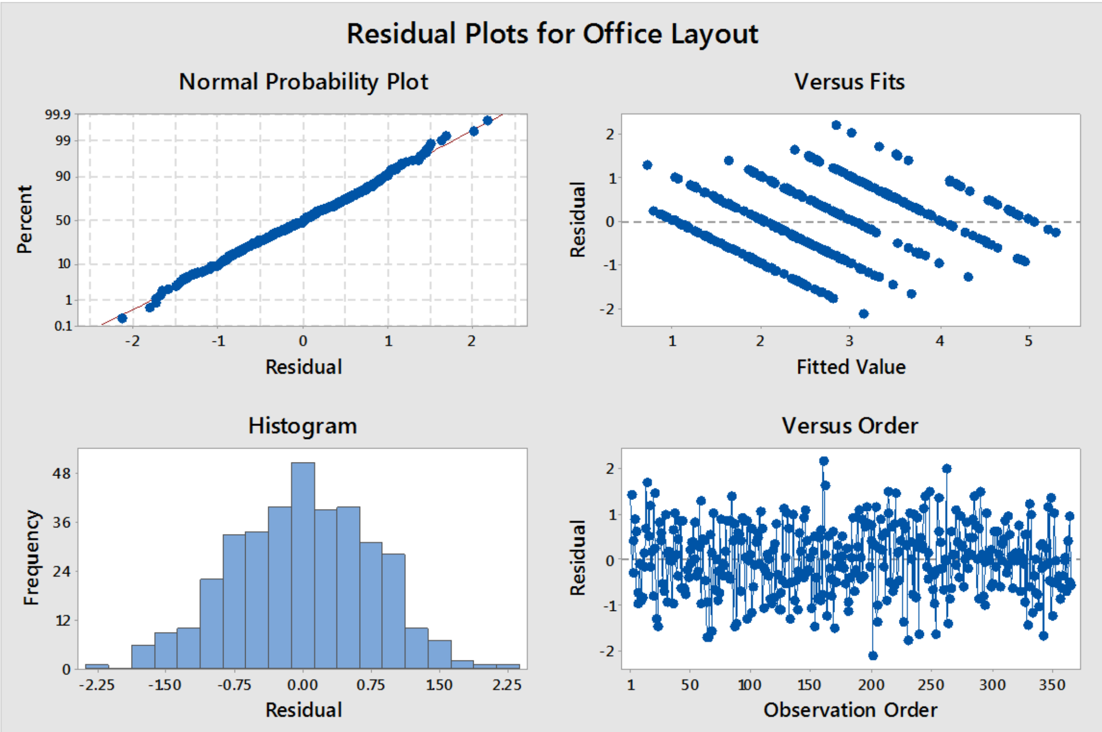


Figure 4.148 - Residual Plots - Office Layout

4.9.3.1 Normal probability

The residuals in the above figure above follow the expected values (mainline). It indicates that the residuals are normally distributed.

4.9.3.2 Versus fits of the fitted value

The scatter of the residuals varies as the fitted value increases. It indicates that residuals are unequal.

4.9.3.3 Residual Histogram

The histogram figure above is observed to be spread over the central area. It is a U-shaped histogram with few outliers. It indicates that data is normally distributed.

4.9.3.4 Residual versus order plot

The residuals in the above figure are between -1 to 1 and suggest no pattern. It indicates that the regression assumptions are satisfied.

4.9.4 Regression Equation

Office Layout = 23.80 - 1.273 Temperature + 0.0907 Relative Humidity
- 0.255 Outside temperature - 0.1697 Outside Relative Humidity
+ 0.01187 CO2
- 0.171 Sound - 0.00908 Light + 0.0304 VOC - 5.46 Kind of Workspace_1
+ 1.81 Kind of Workspace_2 - 7.47 Kind of Workspace_3
+ 8.59 Kind of Workspace_4 + 2.52 Kind of Workspace_5
+ 6.12 Do you sit near (wall type):_1 - 8.52 Do you sit near (wall type):_2
+ 2.78 Do you sit near (wall type):_3 - 0.38 Do you sit near (wall type):_4
+ 0.00660 Outside temperature*Outside temperature
+ 0.000592 Outside Relative Humidity*Outside Relative Humidity
+ 0.02198 Temperature*Sound
+ 0.227 Temperature*Do you sit near (wall type):_1
+ 0.0013 Temperature*Do you sit near (wall type):_2
- 0.0888 Temperature*Do you sit near (wall type):_3
- 0.1393 Temperature*Do you sit near (wall type):_4
+ 0.00355 Outside temperature*Outside Relative Humidity
- 0.00686 Outside temperature*Sound
+ 0.1107 Outside temperature*Kind of Workspace_1
- 0.0305 Outside temperature*Kind of Workspace_2
+ 0.0055 Outside temperature*Kind of Workspace_3
- 0.1020 Outside temperature*Kind of Workspace_4
+ 0.0163 Outside temperature*Kind of Workspace_5
- 0.0425 Outside temperature*Do you sit near (wall type):_1
+ 0.0752 Outside temperature*Do you sit near (wall type):_2
- 0.0563 Outside temperature*Do you sit near (wall type):_3
+ 0.0237 Outside temperature*Do you sit near (wall type):_4

- 0.0114 Outside Relative Humidity*Do you sit near (wall type):_1
+ 0.02568 Outside Relative Humidity*Do you sit near (wall type):_2
- 0.0167 Outside Relative Humidity*Do you sit near (wall type):_3
+ 0.00244 Outside Relative Humidity*Do you sit near (wall type):_4
+ 0.001454 CO2*Kind of Workspace_2 - 0.002076 CO2*Kind of Workspace_3
+ 0.00064 CO2*Kind of Workspace_4 + 0.00026 CO2*Kind of Workspace_5
+ 0.0138 Sound*Kind of Workspace_1 - 0.0349 Sound*Kind of Workspace_2
+ 0.0792 Sound*Kind of Workspace_3 + 0.0296 Sound*Kind of Workspace_4
- 0.0878 Sound*Kind of Workspace_5
- 0.1623 Sound*Do you sit near (wall type):_1
+ 0.0697 Sound*Do you sit near (wall type):_2
+ 0.0396 Sound*Do you sit near (wall type):_3
+ 0.0530 Sound*Do you sit near (wall type):_4
+ 0.00875 Light*Kind of Workspace_1 + 0.00031 Light*Kind of Workspace_2
+ 0.00727 Light*Kind of Workspace_3 - 0.01555 Light*Kind of Workspace_4
- 0.00078 Light*Kind of Workspace_5 + 0.0031 VOC*Kind of Workspace_1
- 0.00205 VOC*Kind of Workspace_2 + 0.0180 VOC*Kind of Workspace_3
- 0.0447 VOC*Kind of Workspace_4 + 0.0256 VOC*Kind of Workspace_5
- 0.0088 VOC*Do you sit near (wall type):_1
+ 0.01844 VOC*Do you sit near (wall type):_2
- 0.01151 VOC*Do you sit near (wall type):_3

4.9.4.1 Equation explanation

The regression equation shows various variables that affect occupant comfort (office layout) and productivity. It shows that temperature, outside temperature, kind of workspace, and wall types influence occupant's comfort (office layout) and productivity. Along with the factors mentioned above, few more linear, square and interactions contribute to the final output.

As part of the analysis, various types of graphs are used to show the impact of different input variable on the output variable.

4.9.5 Pareto chart

A Pareto chart has been used to present the independent variable's magnitude of effect on the output variable (Figure 4.149). The chart has set

1.65 (standardised effect) as the reference line to identify variables that affect occupant comfort (office layout) and productivity.

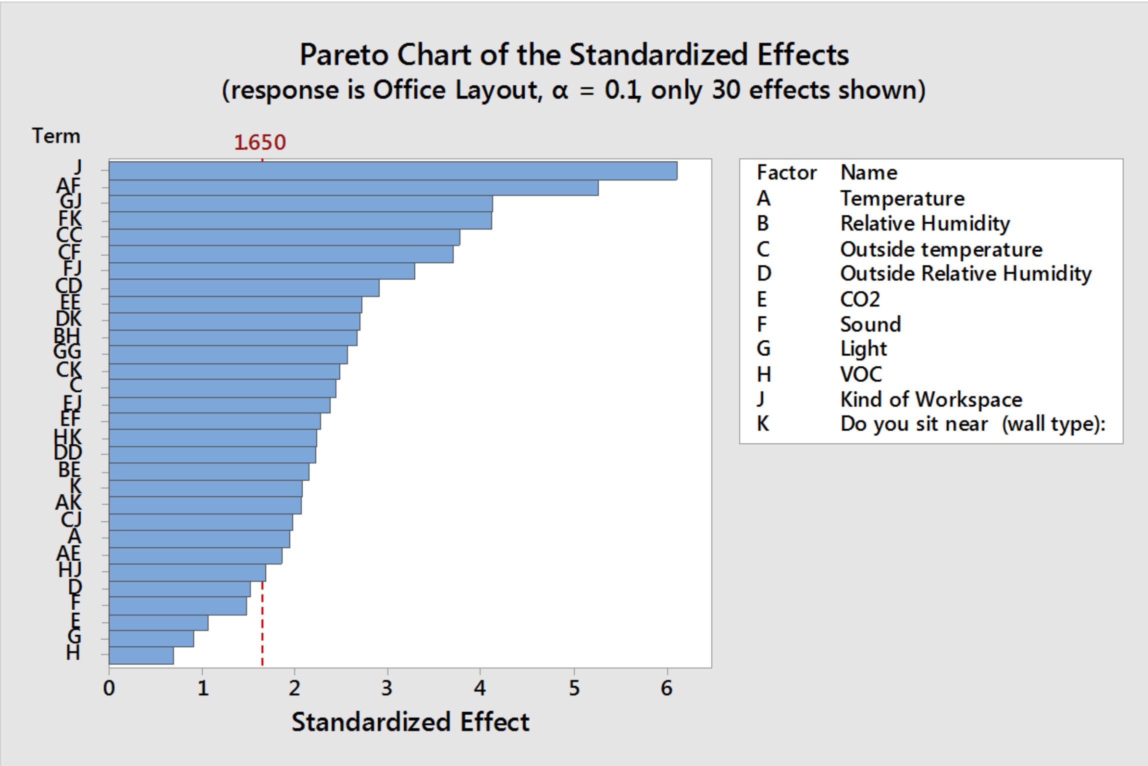


Figure 4.149 - Pareto Chart - Office Layout

Following variables have a significant effect (direct and indirect) on occupant's comfort (office layout) and productivity:

1. Kind of Workspace (maximum effect)
2. Temperature*Sound
3. Light*Kind of workspace
4. Sound*Wall type
5. Outside temperature*Outside temperature
6. Outside temperature*Sound
7. Sound*Kind of workspace
8. Outside temperature*outside relative humidity

The response surface analysis did not produce any relevant contour and surface plots in this analysis.

4.9.6 <u>Summary</u>

This question was aimed at identifying the influence of office layout on occupant productivity and comfort. It also helped to outline interaction and various dependencies between the input variables.

- Type of workspace/office layout affects occupant productivity and comfort.
- It supports the literature findings that suggest that sharing workspace with more people leads to decrease in productivity.
- Workspaces with a higher temperature and sound also have a negative impact on productivity.
- Individual room, non-sharing cubicle have a positive impact on productivity

4.10 Result Summary

The table, below, (Table - 4.9) presents results identified throughout this chapter. It presents the IEQ factor, parameter, their R-square value, their optimum range for maximum achievable productivity and indirect effects and interdependencies on other parameters and factors.

IEQ factor	IEQ parameter	Adjusted R square value	Direct effect	Indirect effects
Thermal comfort	Temperature	74%	Temperature (21-24.5°c)	• Low Lux levels tend to make the occupant feel colder (300 Lux and below) • Low VOC in the air associated with a positive impact on thermal comfort • Sound has an inverse effect on thermal comfort and productivity. Higher dB (55 dB and above) leads to thermal discomfort.
Air Comfort	Natural air (Carbon Dioxide)	87%	• Carbon Dioxide (less than 500 ppm) • VOC (75% and above VOC free air)	• Relative Humidity has a minor effect on indoor air comfort. Higher relative humidity has a negative effect on occupant air comfort and productivity
	Mechanical Ventilation (Carbon Dioxide)	(77%)	• Carbon Dioxide (less than 500 ppm) • VOC (75% and above	• Sound, relative humidity, outside temperature, outside relative humidity have an indirect effect

			VOC free air)	
	VOC	(86%)	VOC (75% VOC free air and above)	• Carbon dioxide (less than 450 ppm), outside relative humidity (higher has a negative impact)
Acoustic comfort	Sound level (dB)	(85%)	Sound level (45dB and below)	• VOC, temperature, outside relative humidity. • Thermally comfortable occupants are observed to have more inertia to identify other discomforts.
Visual Comfort	Illumination levels (Lux)	(82%)	Light level (300 – 450 Lux)	• The outside temperature has a positive correlation with visual comfort. Sunlight leads to the higher outside temperature.
	Natural Light	(96%)	Wall type	• Exterior window – very positive effect • Interior window - positive
Office Layout	Seating Arrangement	(68%)	Kind of workspace	• Individual room, non-sharing cubicle have a positive impact on productivity. • The higher number of people sharing a space leads to lower productivity

Table - 4.9 – Result Summary

5 Discussion

The results of the research are now going to be discussed, highlighting the practical implications for the design and construction industry. It has been divided into six sections. The first section of the chapter presents and discusses the results of thermal comfort response surface analysis. The second section presents the results of indoor air comfort. It outlines and discusses the factors that have an impact on occupant air comfort and productivity. The third section presents the results of the response surface analysis of acoustic comfort. It discusses the effect of sound levels on comfort and productivity. The next section presents and discusses the results of visual comfort, outlining the effect of natural light and lux levels on visual comfort and productivity. Then, there is a reference to office layout and its effect on occupant comfort and productivity, followed by a brief chapter summary.

5.1 Thermal Comfort

The literature review outlined that thermal comfort has a significant influence on occupant comfort and productivity (Lipczynska et al., 2018, Boerstra et al., 2015, Shaharon and Jalaludin, 2012, Nicol et al., 2012, Karjalainen, 2012). A question around thermal comfort question was included in the survey. Response surface analysis led to 0.74 (74%) R-square value (coefficient of determination) indicating a strong relationship between input variables and output variables. It also produced a regression equation that can be used to calculate occupant comfort and productivity by inputting values of input variables. Following variables influence thermal comfort and productivity:

5.1.1 <u>Temperature</u>

This research indicates that temperature has the maximum influence on thermal comfort. It also outlined that 21 – 24.5°c is most productive temperature range. This is coherent with literature findings about temperature and its overall effect on comfort (Seppanen et al., 2006, Karjalainen, 2012, Zhang et al., 2011, Lan et al., 2010, Paul and Taylor, 2008, Tanabe et al., 2007, Bauman and Arens, 1996, ASHRAE, 2010b, ASHRAE, 2005, ASHRAE Standard, 2004). Results also outline that the outside temperature influences occupant productivity. Throughout the experiment, the outside temperature was observed between 20°c to 49°c. This element works in conjunction with indoor temperature. It was observed that optimum comfort and productivity was achieved when the indoor temperature was between 21-24°c and outdoor temperature between 30 - 40°c. Literature also indicated that outdoor temperature affects occupant comfort and productivity (De Dear and Brager, 1998, Humphreys, 1978). However, there is a lack of evidence on the outdoor range and inter-relation with indoor temperature in influencing comfort and productivity. This research outlines inter-relationship between outdoor temperature and indoor temperature. It has also produced the optimum range for the outdoor temperature.

The above findings on indoor and outdoor temperature can be used for the following:

1. To develop design guidelines that assert on maintaining the indoor temperature according to the recommended range by the research. It will help to improve occupant comfort and productivity in offices in Qatar.
2. Research indicated that a higher difference between indoor and outdoor temperature leads to a loss of productivity. Occupant comfort is negatively affected by the higher temperature difference by indoor and outdoor temperature. Specific to the middle-east region, summers are scorching with the temperature reaching up to 50°c. This problem can be solved using the following strategies:
   a. Design a reactive operational guideline for Heating Ventilation and Air - Conditioning System (HVAC) systems that can be used to adapt to the outdoor temperature.
   b. Create buffer zones to reduce the temperature shock for occupant walking in and out of the buildings. This temperature shock creates discomfort for the occupant and increases the time taken by the occupant to adjust and reach an optimum state of thermal comfort. It is recommended to create shaded zones with water bodies around the entrance of the building to create a space that has higher relative humidity and lower temperature than outdoor conditions. It will help to avoid the

temperature shock occupants get while walking in and out of the building.

5.1.2 Relative Humidity

Research results indicate that relative humidity influences occupant thermal comfort and productivity. This result is coherent with the literature on thermal comfort (Langer et al., 2016, Cao et al., 2012, Zhang and Barrett, 2012, Wolkoff and Kjærgaard, 2007). Results indicate that relative humidity between 40 - 60% has a positive impact on occupant thermal comfort and productivity. Outside relative humidity has an indirect influence on thermal comfort. It was observed that low humidity outside associated with low thermal comfort and productivity. In the middle-eastern climate, summers have a high temperature and low relative humidity. Low productivity is reported due to low outside relative humidity, along with the high outside temperature. When analysed in combination with indoor temperature and relative humidity, it was highlighted that the difference between indoor and outdoor relative humidity and temperature leads to lower thermal comfort and productivity.

The above findings on the effect of indoor and outdoor relative humidity can be used for the following:

1. To develop a design and operational guidelines that assert on maintaining indoor relative humidity levels, as concluded in the

research. It would help to improve occupant thermal comfort and productivity in offices in Qatar.

2. Create buffer zones around the entrance of office buildings to provide space that has shade and water bodies. It will also help to provide a space with temperature and relative humidity between the range of temperature and relative humidity to avoid the temperature shock associated with the low thermal comfort and productivity.

5.1.3 Volatile Organic Compound (VOC)

Research results indicate that VOC has an indirect impact on thermal comfort. Currently, there is no research finding that associate VOC with thermal comfort and is a new finding in the realms of thermal comfort and productivity. It indicates that lower VOC levels in the air are associated with a higher level of thermal comfort and productivity. VOC has a positive impact on thermal comfort and productivity when the air is 65% VOC free and above. This finding can be used to propose a design and operation guidelines that assert on maintaining VOC levels as suggested in research findings. It would help to improve thermal comfort and productivity in offices in Qatar.

5.1.4 Light

Research results indicate that lower lux levels are associated with a reduction in thermal comfort. It highlights the indirect effect of occupant's perception of association of lower lux levels with lower temperature and thermal comfort.

This finding can be further investigated in future research endeavours in academia.

5.1.5 Sound

Research results outline that higher levels of sound are associated with lower levels of thermal comfort. Results show that sound levels above 55dB have a negative impact on thermal comfort.

5.2 Indoor Air Comfort

The literature review suggested that indoor air quality influences occupant comfort and productivity (Wolkoff, 2018, Wargocki, 2017, Paul and Taylor, 2008, Kosonen and Tan, 2004, Wargocki et al., 2003, Wargocki, 2000, Fanger, 2000, Fisk et al., 1999, Wargocki et al., 1999, Bauman and Arens, 1996, Bluyssen et al., 1996, Godish and Spengler, 1996, ASHRAE Standard, 1989, ASHRAE Environmental Health Committee, 1987). Indoor air quality was divided into three areas, and three questions were included in the survey. One focused on natural air, the second on mechanical ventilation and the third on VOC. In the case of natural ventilation, response surface analysis led to r-square value (coefficient of determination) of 87%. Mechanical ventilation's response surface analysis led to an r-square value of 77% and 86% for VOC, indicating a substantial relationship between input and output variables in all three questions. The analysis produced regression equations that represent the relationship between input and output variables in both natural and mechanical ventilation. These equations can be used to calculate the occupant indoor air comfort and productivity by inserting filling values of input variables. The following variables affect indoor air comfort and productivity:

5.2.1 Carbon Dioxide

Research results indicate that carbon dioxide levels in indoor air have a negative effect on occupant air comfort and productivity. These results adhere to literature findings that suggest a higher level of carbon dioxide lead to lower occupant comfort (Wolkoff, 2018, Wargocki, 2017, Teichman et al., 2015, Wolkoff, 2013). The results also indicate that carbon dioxide levels up to 500 ppm have a positive effect on occupant comfort and productivity. Currently, the standards suggest that up to 1000 ppm does not have any negative effect on occupant's health (ASHRAE Standard, 1989). However, this research indicates that maintaining carbon dioxide levels below 500 ppm would help to improve occupant productivity. This result can be used to update building regulations and standards in the middle-eastern region. Further research endeavours can be considered in the future to investigate this area.

5.2.2 Volatile Organic Compound (VOC)

Research results outline that VOC has a negative impact on occupant comfort and productivity. It indicates that VOC does not have any negative impact on occupant comfort and productivity till 25% VOC in the air (75% VOC free air by volume). The research experiment results also outlined that up to 15% VOC in the air has a positive effect on occupant comfort and productivity.

5.2.3 <u>Relative Humidity</u>

Research results outlined that the relative humidity influences occupant indoor air comfort and productivity. The results indicate that relative humidity has a positive effect on till 60% indoor relative humidity. Outside temperature also has an indirect effect on air comfort and productivity.

5.2.4 <u>Outside Temperature</u>

Results suggest that up until 36°c, the outside temperature positively affects indoor air comfort. There is no effect of indoor temperature on indoor air comfort, which is a new finding. Currently, no research study outlines any relationship between occupant air comfort and outside temperature. This finding can be further investigated to identify the cause and develop the design and operation recommendations. Based on this finding, the outside temperature can be measured, and the HVAC system can be tuned to counter the increase in outside temperature.

5.2.5 <u>Sound</u>

Results also suggest that the sound level above 55dB have a negative impact on indoor air comfort and productivity. Similar findings were observed with thermal comfort. It suggests that higher sound levels tend to produce dissatisfaction amongst occupants that results in a reduction of overall occupant comfort.

5.3 Acoustic Comfort

The literature review outlined that acoustic comfort influences on occupant productivity (Al horr et al., Paul and Taylor, 2008, Frontczak and Wargocki, 2011, Huang et al., 2012, Jakobsen, 2003, Payne, 2013). A question of acoustic comfort was included in the survey. Response surface analysis showed an r-square value of 0.85 (85%). It indicates that 85% of the data fits the regression and there is a significant relationship between input and output variables. The following factors affect acoustic comfort:

5.3.1 Sound

Research results outline that sound has a positive effect on comfort and productivity up to 45dB. It has a negative effect on 50dB and above. This finding should be specifically implemented in the work areas in an office.

Apart from sound levels, indoor temperature and sound levels have an indirect influence on occupant acoustic comfort and productivity. Results also highlighted a new indirect relationship between thermal comfort and acoustic comfort. Occupants tend to be more sensitive towards sound levels when they are thermally comfortable. It is a new finding and has the potential for further research.

5.4 Visual Comfort

It was found that visual comfort affects occupant productivity (Marans and Yan, 1989, Busch et al., 1993, Veitch, 2001, Reinhart, 2002, Fay et al., 2002, Lim et al., 2017). Visual comfort constitutes illumination levels and access to natural light. The current research outlined that access to natural light has a significant effect on the occupant's visual comfort and productivity (Edwards and Torcellini, 2002, Haans, 2014, Beute and de Kort, 2018). The researcher included two questions on visual comfort. The first question is on illumination levels and second on natural light. Response surface analyses produced an R-square value of 0.84 (84%) for illumination levels and 0.96 (96%) for natural light. It suggests that illumination levels and natural light access have a compelling effect on occupant comfort and productivity. Following factors affect visual comfort and productivity:

5.4.1 Illumination Level (Lux Level)

Research results outline that light levels between 300 – 450 Lux has a positive effect on occupant visual comfort and productivity. Lux levels above and below lead to an adverse effect on occupant comfort and productivity in the workplace.

5.4.2 Natural Light

Research result outlines that the location of the occupant's seat affects access to natural light and visual comfort and productivity. It highlights that occupants seated near internal and external windows are more satisfied with visual comfort and have higher productivity, as compared to the exterior and interior walls.

Amongst other factors, higher external temperature also has a positive correlation with visual comfort. During the daytime, the temperature is higher due to sunlight. It also contributes to higher daylight levels, which can affect indoor illumination.

5.5 Office Layout

The literature review suggested that the office layout affects occupant productivity (Shahzad et al., Haynes, 2008b, Lee, 2010, Haynes, 2007b, Haynes, 2008a, Haynes, 2009). Response surface analysis results show R-square value as 0.62 (62%), indicating that office layout has an impact on occupant productivity. Results suggest that sharing workspaces has an adverse effect on occupant comfort and productivity. It also outlined that workspaces with higher temperature and sound levels have an adverse effect on occupant productivity. It can be concluded that office spaces with more than three occupants have a negative impact on occupant productivity.

This research recommends developing design policy and regulations that promote designing spaces with access to natural light and sharing spaces above three occupants should be avoided. Office design should reflect the office work process.

5.6 Summary

This chapter has presented and discussed the results of the research study. It presented the potential areas of future research. It also highlights the practical benefits of the research results, along with proposed design and policy alterations. Below diagram presents the effect of investigated IEQ factors on occupant productivity along with the ideal range (green), neutral range (yellow), negative range (red).

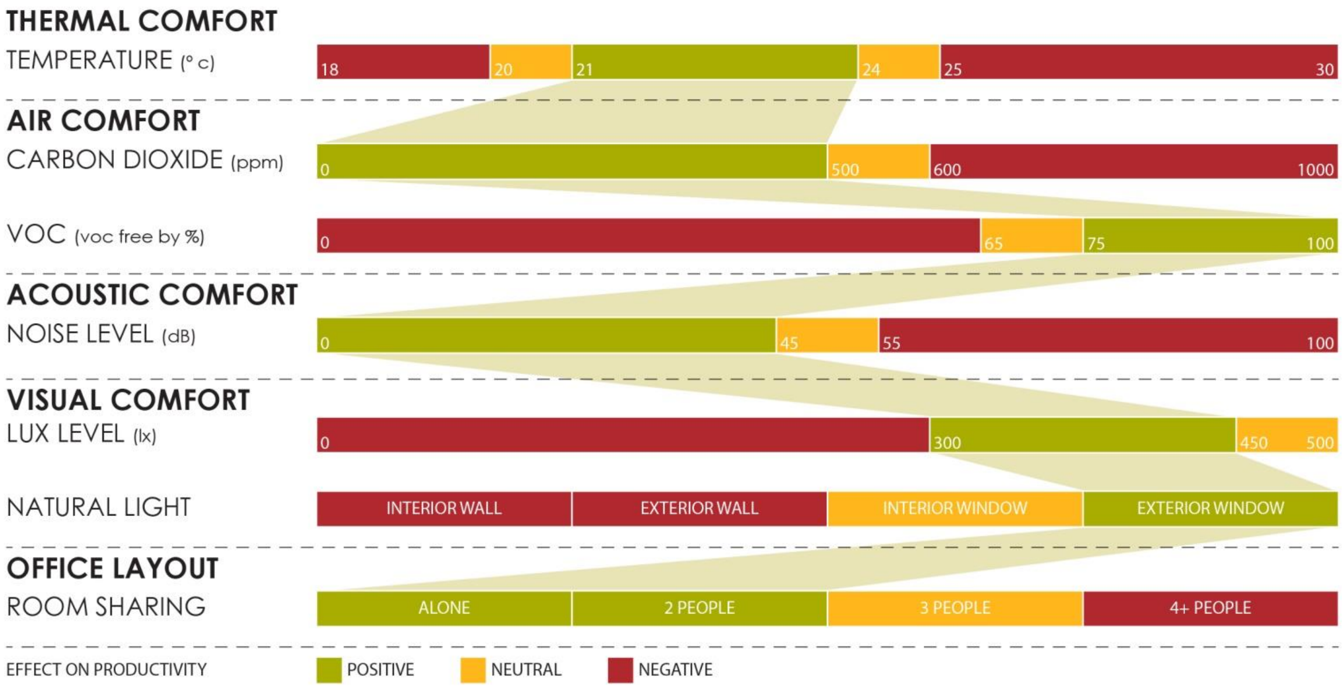


Figure - 5.1Indoor Environmental Quality Factors and their effect on Occupant Productivity

The following chapter presents the conclusion and recommendations.

6 Conclusion and Recommendations

This research study started with the aim of understanding and mapping the effect of indoor environmental quality factors on occupant comfort and productivity in offices in Qatar. As mentioned in the first chapter (section 1.1 and 1.2), there is currently a lack of research and understanding of the effect of indoor environmental quality on occupant comfort and productivity. Building standards and guidelines mainly focus on occupant health and wellbeing but do not explicitly focus on occupant productivity in office buildings. This research study investigated this area by developing a longitudinal experiment and collecting both physical and survey data collections. It also used response surface analysis to analyse data and produce results. The results include the physical indoor environmental quality factors that affect occupant productivity, their recommended ranges and the regression equations that present the direct and indirect relationship between input and output variables in each analysis. This chapter concludes the research study by presenting the main accomplishments and lists some recommendations for practice and further research.

This chapter is divided into six sections. The first section presents the attainment of research objectives of this research, while the second discusses the conclusion of the research. The third part discusses the contribution of the research study. It then outlines contributions to both research and practice. The fourth section presents the limitation of the research, and the fifth present the recommendation for future research. The last section provides a summary of the chapter.

6.1 Research Aim and Objective

This research study set out with the following aim (chapter 1, section 1.3):

"To develop a model that establishes the relationship between indoor environmental quality and occupant productivity in office buildings in Qatar."

The research aim was achieved using a set of five objectives. The breadth of achievement of these objectives is presented below:

1. *To document the indoor environmental quality factors that affects occupant productivity and assesses their impact on occupant productivity in an office environment.*

This objective was achieved by conducting the literature review of indoor environment quality factors and occupant comfort and productivity. A range of literature was reviewed from journal articles, conference proceedings and 300 references, dated 1920 to 2018. The literature led to the identification of five indoor environmental quality factors that influence occupant comfort and productivity. These are Thermal Comfort (Temperature, Relative Humidity), Air Comfort (Carbon Dioxide, Volatile Organic Compound), Acoustic Comfort (Sound levels), Visual Comfort (Lux level, Natural light), Office Layout (Cubicle, Shared room). This objective achievement can be found in detail in chapter two.

2. *To document metrics and methodologies, those assess indoor environmental quality and occupant productivity in an office building.*

   This objective was achieved by reviewing the literature on different metrics and methodologies used to assess indoor environmental quality factors and occupant comfort and productivity in office buildings. Literature ranged from journal articles to books and led to the development of data collection and analysis framework that was used in this research study. The research study used Post Occupancy Evaluation (POE) along with Quantitative data collection and analysis using sensors that measure indoor environmental quality parameters. It was done in a longitudinal format. This objective achievement can be found in detail in chapter three.

3. *To establish a relationship model (set of equations) between indoor environmental quality and employee productivity in an office building.*

   This objective was achieved by conducting a response surface analysis of different parameters under each indoor environmental factor and their individual responses to the survey. Each regression equation represents the relationship between occupant productivity and comfort and various indoor environmental quality factors. These equations are:

Thermal Comfort = -52.08 + 5.666 Temperature - 0.1318 Relative Humidity
- 0.015 Outside temperature - 0.0836 Outside Relative Humidity
+ 0.00637 CO2 - 0.2088 Sound - 0.00460 Light - 0.0468 VOC
+ 1.53 Kind of Workspace_1 + 1.536 Kind of Workspace_2
+ 2.79 Kind of Workspace_3 - 6.17 Kind of Workspace_4
+ 0.32 Kind of Workspace_5 + 0.37 Do you sit near (wall type):_1
+ 0.424 Do you sit near (wall type):_2
- 0.484 Do you sit near (wall type):_3
- 0.307 Do you sit near (wall type):_4 - 0.11728 Temperature*Temperature
+ 0.000460 Relative Humidity*Relative Humidity
- 0.003066 Outside temperature*Outside temperature
+ 0.000363 Outside Relative Humidity*Outside Relative Humidity
- 0.000270 Temperature*CO2 + 0.001846 Relative Humidity*Outside temperature
- 0.0381 Relative Humidity*Do you sit near (wall type):_1
+ 0.01842 Relative Humidity*Do you sit near (wall type):_2
+ 0.01876 Relative Humidity*Do you sit near (wall type):_3
+ 0.00094 Relative Humidity*Do you sit near (wall type):_4
+ 0.00313 Outside temperature*Sound
- 0.0217 Outside temperature*Kind of Workspace_1
- 0.0252 Outside temperature*Kind of Workspace_2
+ 0.0074 Outside temperature*Kind of Workspace_3
+ 0.1010 Outside temperature*Kind of Workspace_4
- 0.0614 Outside temperature*Kind of Workspace_5
+ 0.001164 Outside Relative Humidity*Sound
+ 0.000838 CO2*Kind of Workspace_1 - 0.001454 CO2*Kind of Workspace_2
+ 0.001355 CO2*Kind of Workspace_3 - 0.00248 CO2*Kind of Workspace_4
+ 0.00174 CO2*Kind of Workspace_5 + 0.000736 Sound*VOC
- 0.0246 Sound*Kind of Workspace_1 + 0.0055 Sound*Kind of Workspace_2
- 0.0562 Sound*Kind of Workspace_3 + 0.0600 Sound*Kind of Workspace_4
+ 0.0154 Sound*Kind of Workspace_5 + 0.000073 Light*VOC
- 0.00044 Light*Kind of Workspace_1 + 0.00107 Light*Kind of Workspace_2
- 0.00290 Light*Kind of Workspace_3 + 0.00376 Light*Kind of Workspace_4
- 0.00150 Light*Kind of Workspace_5
+ 0.0293 VOC*Do you sit near (wall type):_1
- 0.02088 VOC*Do you sit near (wall type):_2
- 0.00733 VOC*Do you sit near (wall type):_3
- 0.00107 VOC*Do you sit near (wall type):_4

Natural fresh air = -1.26 - 0.01210 CO2 + 0.0577 VOC -
- 0.0768 Temperature + 0.2483 Outside temperature
+ 0.0773 Outside Relative Humidity + 0.1024 Sound
- 2.25 Kind of Workspace_1 + 0.95 Kind of Workspace_2
- 1.25 Kind of Workspace_3 - 1.16 Kind of Workspace_4
+ 3.71 Kind of Workspace_5 + 0.167 Do you sit near (wall type):_1
+ 0.230 Do you sit near (wall type):_2+ 0.064 Do you sit near (wall type):_3
- 0.460 Do you sit near (wall type):_4
+ 0.01855 VOC*Do you sit near (wall type):_1

- 0.02564 Relative Humidity*Do you sit near (wall type):_1
+ 0.1041 Temperature*Kind of Workspace_1+ 0.1213 Temperature*Kind of Workspace_2+ 0.0395 Temperature*Kind of Workspace_3+ 0.0914 Temperature*Kind of Workspace_4 - 0.356 Temperature*Kind of Workspace_5 - 0.0152 Outside temperature*Kind of Workspace_1- 0.0462 Outside temperature*Kind of Workspace_2
+ 0.0136 Outside temperature*Kind of Workspace_3
- 0.0214 Outside temperature*Kind of Workspace_4
+ 0.0691 Outside temperature*Kind of Workspace_5
- 0.01459 Outside Relative Humidity*Kind of Workspace_1
- 0.01438 Outside Relative Humidity*Kind of Workspace_2
+ 0.0259 Outside Relative Humidity*Kind of Workspace_5

Mechanical Ventilation = 1.27 - 0.00785 CO2 + 0.0319 VOC + 0.00913 Relative Humidity
- 0.370 Temperature + 0.1035 Outside temperature
+ 0.0353 Outside Relative Humidity + 0.1930 Sound + 0.01239 Light
- 0.863 Kind of Workspace_1 - 0.306 Kind of Workspace_2
+ 1.322 Kind of Workspace_3 + 0.47 Kind of Workspace_4
- 0.621 Kind of Workspace_5 + 1.658 Do you sit near (wall type):_1
+ 0.241 Do you sit near (wall type):_2
- 0.448 Do you sit near (wall type):_3
- 1.451 Do you sit near (wall type):_4 + 0.000005 CO2*CO2
- 0.002431 Sound*Sound - 0.000028 CO2*VOC - 0.000007 CO2*Light
- 0.000059 VOC*Light - 0.00622 VOC*Kind of Workspace_1
+ 0.00142 VOC*Kind of Workspace_2 - 0.01523 VOC*Kind of Workspace_3
+ 0.01692 VOC*Kind of Workspace_4
+ 0.0031 VOC*Kind of Workspace_5
- 0.000052 Relative Humidity*Light + 0.00731 Temperature*Sound
- 0.00262 Outside temperature*Sound
- 0.0872 Outside temperature*Do you sit near (wall type):_1
+ 0.0055 Outside temperature*Do you sit near (wall type):_2
+ 0.0324 Outside temperature*Do you sit near (wall type):_3
+ 0.0492 Outside temperature*Do you sit near (wall type):_4
- 0.000750 Outside Relative Humidity*Sound
- 0.01780 Outside Relative Humidity*Do you sit near (wall type):_1
+ 0.00213 Outside Relative Humidity*Do you sit near (wall type):_2
+ 0.00640 Outside Relative Humidity*Do you sit near (wall type):_3
+ 0.00927 Outside Relative Humidity*Do you sit near (wall type):_4
+ 0.00434 Light*Kind of Workspace_1
+ 0.000673 Light*Kind of Workspace_2
- 0.00167 Light*Kind of Workspace_3
- 0.00469 Light*Kind of Workspace_4
+ 0.00134 Light*Kind of Workspace_5
+ 0.00759 Light*Do you sit near (wall type):_1
- 0.001385 Light*Do you sit near (wall type):_2
- 0.003425 Light*Do you sit near (wall type):_3
- 0.002782 Light*Do you sit near (wall type):_4

Indoor chemical and pollutant	=	2.5775 + 3.968 VOC - 0.289 Relative Humidity*Relative Humidity + 0.237 Sound*Sound - 0.930 VOC*VOC - 0.343 Outside temperature*Light + 0.412 Outside Relative Humidity*CO2 + 0.459 Outside Relative Humidity*VOC- 0.214 Outside Relative Humidity*Do you sit near (wall type):_1 - 0.0560 Outside Relative Humidity*Do you sit near (wall typ e):_2+ 0.037 Outside Relative Humidity*Do you sit near (wall type):_3 sit near (wall type) - 0.283 Sound*Do you sit near (wall type):_4 + 0.400 CO2*VOC + 0.083 CO2*Do you sit near (wall type):_1 - 0.3182 CO2*Do you sit near (wall type):_2 + 0.159 CO2*Do you sit near (wall type):_3 + 0.076 CO2*Do you sit near (wall type):_4 - 0.534 Light*Kind of Workspace_1 + 0.310 Light*Kind of Workspace_2 - 0.055 Light*Kind of Workspace_3 - 0.188 Light*Kind of Workspace_4 + 0.466 Light*Kind of Workspace_5 + 0.215 VOC*Do you sit near (wall type):_1 - 0.362 VOC*Do you sit near (wall type):_2 + 0.277 VOC*Do you sit near (wall type):_3 - 0.131 VOC*Do you sit near (wall type):_4

Acoustic quality = 26.65 - 0.5323 Sound + 0.00348 Light + 0.0509 VOC - 0.890 Temperature
+ 0.0427 Outside temperature + 0.02693 Outside Relative Humidity
+ 0.001642 CO2 + 2.87 Kind of Workspace_1 - 0.222 Kind of Workspace_2
+ 0.193 Kind of Workspace_3 - 1.77 Kind of Workspace_4
- 1.07 Kind of Workspace_5 - 0.504 Do you sit near (wall type):_1
+ 0.309 Do you sit near (wall type):_2
+ 0.267 Do you sit near (wall type):_3
- 0.073 Do you sit near (wall type):_4 + 0.005809 Sound*Sound
- 0.000312 VOC*VOC + 0.02229 Temperature*Temperature -
0.000809 Sound*VOC
- 0.00700 Sound*Temperature - 0.000006 Light*CO2
+ 0.001758 VOC*Temperature - 0.0668 Temperature*Kind of Workspace_1
+ 0.0722 Temperature*Kind of Workspace_2
+ 0.0710 Temperature*Kind of Workspace_3
+ 0.1208 Temperature*Kind of Workspace_4
- 0.1972 Temperature*Kind of Workspace_5
- 0.000453 Outside temperature*Outside Relative Humidity
- 0.0147 Outside temperature*Kind of Workspace_1
- 0.0374 Outside temperature*Kind of Workspace_2
- 0.0373 Outside temperature*Kind of Workspace_3
- 0.0307 Outside temperature*Kind of Workspace_4
+ 0.1201 Outside temperature*Kind of Workspace_5
- 0.02028 Outside Relative Humidity*Kind of Workspace_1
- 0.00671 Outside Relative Humidity*Kind of Workspace_2
- 0.01333 Outside Relative Humidity*Kind of Workspace_3
- 0.00297 Outside Relative Humidity*Kind of Workspace_4
+ 0.0433 Outside Relative Humidity*Kind of Workspace_5
+ 0.01123 Outside Relative Humidity*Do you sit near (wall type):_1
- 0.00723 Outside Relative Humidity*Do you sit near (wall type):_2
- 0.00389 Outside Relative Humidity*Do you sit near (wall type):_3
- 0.00011 Outside Relative Humidity*Do you sit near (wall type):_4

Artificial light level = -0.42 + 0.01601 Light + 0.580 Temperature - 0.00767 Relative Humidity
- 0.1898 Outside temperature - 0.0960 Outside Relative Humidity
- 0.00173 CO2 + 0.01316 Sound - 0.0064 VOC
+ 0.150 Kind of Workspace_1 + 0.376 Kind of Workspace_2
- 0.659 Kind of Workspace_3 - 0.185 Kind of Workspace_4
+ 0.318 Kind of Workspace_5 - 1.219 Do you sit near (wall type):_1
- 0.023 Do you sit near (wall type):_2
+ 1.183 Do you sit near (wall type):_3
+ 0.058 Do you sit near (wall type):_4 - 0.000012 Light*Light
- 0.01097 Temperature*Temperature - 0.000313 VOC*VOC
- 0.000164 Temperature*CO2
+ 0.000448 Relative Humidity*Outside Relative Humidity
- 0.00338 Relative Humidity*Kind of Workspace_1
- 0.00745 Relative Humidity*Kind of Workspace_2
+ 0.00844 Relative Humidity*Kind of Workspace_3
+ 0.0053 Relative Humidity*Kind of Workspace_4
- 0.00295 Relative Humidity*Kind of Workspace_5
+ 0.000144 Outside temperature*CO2 + 0.001424 Outside temperature*VOC
+ 0.0348 Outside temperature*Do you sit near (wall type):_1
- 0.00204 Outside temperature*Do you sit near (wall type):_2
- 0.0326 Outside temperature*Do you sit near (wall type):_3
- 0.00024 Outside temperature*Do you sit near (wall type):_4
+ 0.000069 Outside Relative Humidity*CO2
+ 0.000432 Outside Relative Humidity*VOC - 0.000035 CO2*VOC

Natural light = 7.66 - 0.000514 Light - 0.253 Temperature - 0.00286 Relative Humidity
- 0.0259 Outside temperature - 0.0507 Outside Relative Humidity
- 1.086 Kind of Workspace_1 - 0.844 Kind of Workspace_2
- 0.531 Kind of Workspace_3 + 0.120 Kind of Workspace_4
+ 2.340 Kind of Workspace_5 - 0.856 Do you sit near (wall type):_1
- 2.220 Do you sit near (wall type):_2
+ 2.415 Do you sit near (wall type):_3
+ 0.662 Do you sit near (wall type):_4 + 0.00496 Temperature*Temperature
+ 0.000308 Outside Relative Humidity*Outside Relative Humidity
- 0.000015 Light*Do you sit near (wall type):_1
+ 0.000412 Light*Do you sit near (wall type):_2
- 0.001110 Light*Do you sit near (wall type):_3
+ 0.000713 Light*Do you sit near (wall type):_4
+ 0.0430 Temperature*Kind of Workspace_1
+ 0.0377 Temperature*Kind of Workspace_2
+ 0.0237 Temperature*Kind of Workspace_3
- 0.0056 Temperature*Kind of Workspace_4
- 0.0988 Temperature*Kind of Workspace_5
- 0.00002 Relative Humidity*Do you sit near (wall type):_1
+ 0.00539 Relative Humidity*Do you sit near (wall type):_2
- 0.00676 Relative Humidity*Do you sit near (wall type):_3
+ 0.00139 Relative Humidity*Do you sit near (wall type):_4
+ 0.000771 Outside temperature*Outside Relative Humidity

4. *To outline the inter-dependencies of various indoor environmental factors affecting occupant comfort and productivity.*

   This objective was achieved through data analysis. Response surface methodology and Pareto charts outlined different factors that had inter-dependencies on each other while affecting the overall occupant comfort and productivity. These interdependencies are listed in chapter four and discussed in chapter five.

5. *To develop suggestions and recommendations for the built environment professionals to incorporate occupant productivity and indoor environmental quality in office design.*

   This objective was achieved in the discussion chapter (chapter five). The contributions and recommendations of the research are presented in the forthcoming sections in this chapter. Design recommendations are listed below:

IEQ factor	Design Recommendations
Thermal Comfort	Create **buffer zones** to reduce **temperature shock** – Create shaded zones with water bodies around building an entrance to create low temperature and high humidity area.
Indoor Air Comfort	Use of **indoor plants** (air cleaning) in office zones away from fresh air supply fans in the building (Air cleaning + Biophilia)
Acoustic Comfort	Use of **Masking noise** in PA speakers to reduce noise spikes Semi-permeable screens in open plan zone to improve acoustics
Visual Comfort	Orient office layout to allow **maximum sunlight** into the floor area

	Use of **translucent glass** for rooms to improve light dispersion
Office Layout	Design and use **storage units** to create privacy yet maximum use of the space

Table 6.1 – Design Recommendations

6.1.1 Holistic View

These design recommendations are the outcomes of the research study. They are highly applicable and beneficial in improving occupant comfort and productivity in an office environment in Qatar. However, these recommendations should not be considered in isolation. All the above design recommendations are based on indoor environmental parameters that constitute the indoor environment of an office. They all have a direct and indirect impact on each other, and proposed design recommendation should be applied with a holistic view and understanding of the context. For instance, allowing maximum sunlight to gain visual comfort can increase temperature and reduction in humidity. It can create an impact on occupant's thermal comfort. Indirect sunlight can be gained from the South and North side due to the high angle of the sun and avoided from East or West. It will result in improving the visual comfort yet have not the significant impact of the thermal environment of space. It is also easy to block the high sun in the North and South using small overhangs. It also helps in reducing electricity usage for maintaining the thermal environment.

Similarly, office layout design to create privacy using storage unit might create some local 'cold spots' in the office. These areas have a lower temperature than overall office temperature. It can be avoided by designing the air-conditioning supply while considering the office layout, high storage unit and partition walls.

Indoor Air Comfort is improved by using indoor plants and is beneficial for occupant comfort and productivity. However, if we place too many indoor plants, they may affect the relative humidity of the space and thus affecting the thermal comfort of the occupants. Hence, indoor plants should be uniformly placed with careful consideration of air changes set in the air-conditioning system.

Above examples present situations that underline the significance of holistic view while applying the design recommendations in an office building.

6.2 Conclusion of Research

Here is a summary of the main conclusions drawn from this research study. There are primarily five conclusions:

1) The research started with investigating the degree of impact of indoor environmental quality factors on occupant productivity in an office building. It focused on Doha, Qatar, due to its importance of being one of the most developing capitals and overall region's growth in similar climatic-region. Literature helped to list the main factors that influence

occupant comfort and productivity. It confirmed that indoor environmental factors have a significant impact on occupant productivity. It also presented the complexity of measuring and understanding comfort and productivity. Comfort is a direct response to the physical parameters. Comfort range for any physical parameter ranges from person to person. It also highlighted the lack of direct focus on occupant productivity in building standards and design guidelines. Comfort and productivity do not usually overlap entirely, as comfort range is broader than productivity range. It is not necessary that comfortable occupants are productive in the entire range, a finding that was also confirmed in the research results. In case of temperature, the widely accepted comfortable range is 21°c - 26°c. However, the maximum productivity range is from 21°c – 24°c.

2) Similarly, standards recommend carbon dioxide levels to be 1000 ppm or below for comfortable and healthy indoor air quality. However, research results suggest that carbon dioxide had a positive impact on productivity up to 500 ppm. In case of light, a person can see clearly from 100 lux, but research results outlined that 350 – 500 lux range to be positive for occupant productive. All the guidelines are designed to focus on comfort and well-being. They recommend ranges for different physical parameters based on studies conducted in a single type of climate. A lot of these ranges are vague and had received a spectrum of response when tested on different occupant profiles. There is a need to improve the

classification and focus of different building standards and guidelines based on climate and occupant profile.

3) One of the significant results of the research study is the recommended levels (section 4.9) of the productive range of indoor environmental quality factors.

    a. Temperature - 21-24.5°c
    b. Relative Humidity – 40-60%
    c. Carbon Dioxide – Below 550 ppm
    d. VOC – 75% VOC Free air (volume)
    e. Lux levels – 300 – 450 Lux
    f. Natural light: Access to direct natural light via a direct window or indirect access through atrium etc.
    g. Sound levels – up to 45 dB
    h. Office layout:
        i. Sharing up to three people
        ii. A room with good acoustics can be shared while avoiding open plan

Currently, no building guidelines and standards have a recommended range for different indoor environmental quality factors focusing on occupant productivity. This research experiment and results are the first of its kind to investigate and prescribe a recommended range of productivity in offices.

Building guidelines in the middle-east region are suggested to adopt recommended ranges from this research study.

4) The research results have also outlined the inter-dependencies of different indoor environmental quality factors and indirect effects on occupant productivity. Some of the inter-dependencies were identified in the literature, and some were identified in the experiment. These are presented and discussed in chapter five. These unique cases of one physical parameter affecting other factor and its impact on occupant productivity provide a significant opportunity for future research endeavours in the field of indoor environmental quality and occupant comfort and productivity.

5) This research study aimed to develop a mathematical model that would present the relationship between occupant productivity and indoor environmental quality factors. The study produced eight equations addressing eight indoor environment parameters under five indoor environmental quality factors. These equations can be used to calculate occupant productivity for each of the indoor environmental factors. Design industry professionals in Qatar can use these equations. They also provide an excellent example for researchers to investigate similar types of relationship in other types of buildings and climate zones.

6.3 Contribution of Research

This section outlines the contributions of this research study. This research study has different contributions in both industry and academia.

6.3.1 Contribution to Industry

The following are the contributions to the industry:

1) This research study is one of the first to analyse indoor environmental quality factors focusing on occupant productivity in an office building in the middle-east region. It will help to provide a comprehensive understanding of occupant productivity and its relevance in office design for any design professional in Qatar and has provided some design recommendations that would be beneficial to built environment professionals to design health and productive buildings for office occupants in Qatar.

2) The mathematical model (set of equations) produced in the study can be used by industry professionals to design office spaces with higher occupant productivity and satisfaction levels. These equations can be incorporated in design guidelines in the middle- east region.

3) The recommended range of indoor environmental quality factors produced in the research study can be used to improve current building standards and office design guidelines in Qatar.

4) This study provides future research and development direction for the green building rating system across the globe. Currently, no building rating system outlines the IEQ factors that influence occupant productivity. Green building guidelines focus on reducing energy consumption and carbon footprint. This research study would be a unique effort to contributete a robust study for researchers to develop new criteria for green building rating systems and update the guidelines for office buildings.

6.3.2 Contribution to Knowledge

This research study makes the following contributions to knowledge:

1. It provided a significant new contribution to existing knowledge on occupant productivity and indoor environmental quality. It has produced some useful literature that adds to the knowledge of indoor environmental quality on five physical factors.

2. It has highlighted various inter-dependencies and indirect effect of occupant comfort and productivity. These unique relationships are new to the literature and provide an excellent starting point for researchers in this area of indoor environmental quality.

3. It has contributed to the existing knowledge of metrics and methodologies that analyse the impact of indoor environmental factor on occupant comfort in an office building. Data collection was done

by the latest compact wireless sensors, and data analysis was done using response surface methodology.

4. This study is first of its kind and provides as a strong illustration to conduct similar studies in different types of buildings such as schools, universities and hospitals to improve productivity and comfort. It can also be conducted in a different type of climate zones.
5. This study presented various mathematical equations for different types of comfort and productivity that establish the relationship between indoor environmental quality and occupant productivity. These models can be used as a significant starting point for architectural environment researchers for new research endeavours in a similar subject area.

6.4 Limitations of Research

The purpose of this research was to investigate indoor environmental quality factors and their effect on occupant productivity in office buildings in Qatar. It would help to improve the building design and operation in Qatar and improve occupant comfort and productivity. Summarised below are the limitations of the study:

1. The focus of the research study is limited to the physical environmental factors and doesn't include behavioural factors. The behavioural and emotional health of an occupant influences their comfort and productivity in offices. However, these non-physical factors are challenging to measure and may fluctuate rapidly and vary person to

person. So, the non-physical dimension of the environment wasn't included in the study. It also has to be noted that the results of this study would be used in an office with similar non-physical factors with no control. Although it is a limitation, the applicability of the results is still valid and robust.

2. Occupant productivity was calculated based on occupant survey. The organisation refused to share any performance measurement mechanism, due to privacy and confidentiality issues. Literature suggests that an occupant tends to respond positively to productivity questions. It was addressed by changing the question from 'how productive are you?' to 'how has the following indoor environmental factor affected your productivity?'

3. This research has only focused on office buildings in Doha, Qatar, with middle-eastern climatic conditions. Its results are only applicable to buildings in similar climatic conditions.

6.5 Recommendation of Future Research

1. This research provides a robust starting point for researchers to investigate indoor environmental quality and occupant productivity. It can be used as an example and applied to investigate similar relationships in different types of buildings in various types of climatic conditions.

2. The regression equations provide a good starting point to investing second and third level inter-dependencies between different indoor environmental quality factors. Researchers can analyse equations to underline more of such relationships.

3. The recommended range of current results should be used to update green building guidelines in the middle-east region. Future research can be conducted using pilot studies in office buildings.

4. This research experiment was conducted using wireless sensors and online data collection, storage system. It is one of the first studies to use response surface methodology to develop regression equations and list the inter-dependencies in the area of occupant comfort and productivity. The elevation in technology-enabled this research to achieve its unique aim and objectives. It also provides an opportunity to tap into other emergent technologies, such as Building Information Modelling (BIM), City Information Modelling (CIM), and Big Data

analysis, Cloud computing and Geographical Information Systems (GIS).

a. Efficient use of BIM and GIS is already used to manage big buildings, campus and IT parks. They are used to collect occupant data and analyse the occupancy pattern in both visual and data formats. It helps to change the building management system from a reactive system to a proactive system, regarding energy efficiency and occupant security. Results from this research combined with a SMART building management system that uses BIM and GIS system can be used to manage indoor environmental quality parameters and promote a healthy and productive indoor environment in commercial and educational building complexes in Qatar.

b. A similar combination of emergent technologies can be used to create a SMART city model. There is a potential to apply CIM, BIM, GIS and Big Data Analytics along with research output from this research to improve the productivity at the city level in Doha, Qatar. Commercial buildings in Doha can apply these research results and recommendations to design and operate at prescribed levels of indoor environmental factors. A graphical and data model (BIM) can be developed and connect using CIM data systems can potentially provide a city level operational model for connected buildings with access to data such as energy usage (volume and type), occupancy habit and pattern. This, combined with analysis of their response to online city level survey to indoor environment's quality, can lead to developing a SMART city model that interacts with its office workers to improve their productivity. This framework will require setting up at different levels, but the financial, health and social benefits at the city level would significantly help the national growth of Qatar.

6.6 Summary

This chapter has presented the conclusion and recommendations of this research study. It first outlines the achievement of the research aim and objectives. All the objectives were met, and thus, the aim of the research study was also achieved. The following part presented and explained five conclusions of the research study, including an outline of the five strands of conclusions. These were in the area of understanding and knowledge of indoor environmental quality and complexity of measuring it, recommended levels of indoor environmental quality factors and the importance of including them in green building guidelines, interdependences of various indoor environmental factors. The contributions of research in both industry and knowledge have been presented, followed by an outline of the limitations of the research. Finally, future research recommendations have been put forward.

7 References

<Cpaturing the daylight divided in buildings_why and how.pdf>.

(AMA), A. M. A. 2004. AMA Workware Toolkit: Case Study Department of Health Office Evaluation.

Abdulkareem, H. A. 2016. Thermal comfort through the microclimates of the courtyard. A critical review of the middle-eastern courtyard house as a climatic response. *Procedia-Social and Behavioral Sciences,* 216**,** 662-674.

Akimoto, T., Tanabe, S.-i., Yanai, T. & Sasaki, M. 2010. Thermal comfort and productivity-Evaluation of workplace environment in a task conditioned office. *Building and Environment,* 45**,** 45-50.

Al-ajmi, F. F. 2010. Thermal comfort in air-conditioned mosques in the dry desert climate. *Building and Environment,* 45**,** 2407-2413.

Al-Emadi, A., Kaplanidou, K., Diop, A., Sagas, M., Le, K. T. & Al-Ali Mustafa, S. 2017. 2022 Qatar World Cup: Impact Perceptions among Qatar Residents. *Journal of Travel Research,* 56**,** 678-694.

Al horr, Y., Arif, M., Katafygiotou, M., Mazroei, A., Kaushik, A. & Elsarrag, E. Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *International Journal of Sustainable Built Environment*.

Al Touma, A. & Ouahrani, D. 2018. The selection of brise soleil shading optical properties for energy conservation and glare removal: A case study in Qatar. *Journal of Building Engineering,* 20**,** 510-519.

Alcântara, S. R., da Silva, F. L. & Leite, N. J. 2013. *Scale Up of Polygalacturonase Production by Solid State Fermentation Process*, INTECH Open Access Publisher.

Allen, I. E. & Seaman, C. A. 2007. Likert scales and data analyses. *Quality progress,* 40**,** 64.

Almfraji, M. A., Almsafir, M. K. & Yao, L. 2014. Economic Growth and Foreign Direct Investment Inflows: The Case of Qatar. *Procedia - Social and Behavioral Sciences,* 109**,** 1040-1045.

Alrubaih, M. S., Zain, M. F. M., Alghoul, M. A., Ibrahim, N. L. N., Shameri, M. A. & Elayeb, O. 2013. Research and development on aspects of daylighting fundamentals. *Renewable and Sustainable Energy Reviews,* 21**,** 494-505.

Alzubaidi, S., Roaf, S., Banfill, P., Talib, R. A. & Al-Ansari, A. 2013. Survey of hospitals lighting: Daylight and staff preferences. *International Journal of Energy Engineering,* 3**,** 287-293.

Amasyali, K. & El-Gohary, N. M. 2016. Energy-related values and satisfaction levels of residential and office building occupants. *Building and Environment,* 95**,** 251-263.

Arens, E. A., Xu, T., Miura, K., Zhang, H., Fountain, M. & Bauman, F. 1997. A study of occupant cooling by personally controlled air movement.

Aries, M. B. C. 2005. *Human lighting demands: healthy lighting in an office environment*. Technische Universiteit Eindhoven.

ASHRAE 1993. ASHRAE Fundamentals - Handbook. *Atlanta*.

ASHRAE 2004. Standard 55-2004, Thermal environmental conditions for human occupancy. *American Society of Heating, Refrigerating and Air-Conditioning Engineering, Atlanta, GA*.

ASHRAE 2005. ASHRAE handbook of fundamentals. *American Society of Heating, Refrigerating and Air Conditioning Engineers.* Atlanta, Georgia, USA: ASHRAE.

ASHRAE 2010a. ASHRAE Standard 55. *Thermal Environmental Conditions for Human Occupancy.* Atlanta: Inc.

ASHRAE 2010b. ASHRAE Standard 55. *Thermal Environmental Conditions for Human Occupancy.* Atlanta: Inc.

ASHRAE Environmental Health Committee 1987. Indoor Air Quality Position Paper. *Atlanta, GA: American Society of Heating, Refrigeration, and AirConditioning Engineers*.

ASHRAE Standard 1989. Standard 62-1999, Ventilation for Acceptable Indoor Air Quality. *American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, Ga*.

ASHRAE Standard 1992. Standard 55-1992. *Thermal environmental conditions for human occupancy*.

ASHRAE Standard 2004. Standard 55-2004. *Thermal environmental conditions for human occupancy*.

Association, A. C. 2011. An introduction to indoor air quality (IAQ): Volatile Organic Compounds (VOCs), Washington DC, USA; 2011.

Attia, S. & Carlucci, S. 2015. Impact of different thermal comfort models on zero energy residential buildings in hot climate. *Energy and Buildings,* 102**,** 117-128.

Ayr, U., Cirillo, E., Fato, I. & Martellotta, F. 2003. A new approach to assessing the performance of noise indices in buildings. *Applied Acoustics,* 64**,** 129-145.

Baker, N. & Steemers, K. 2003. *Energy and environment in architecture: a technical design guide*, Taylor & Francis.

Banbury, S. & Berry, D. 2005. Office noise and employee concentration: Identifying causes of disruption and potential improvements. *Ergonomics,* 48**,** 25-37.

Bank, W. 2014. *World development indicators 2014*, World Bank Publications.

Bauman, F. S. P. E. & Arens, E. A. P. D. 1996. Task/ambient conditioning systems: Engineering and application guidelines.

Bazewicz, M. 2000. The axiological foundation of the nature value of information. *The,* 10**,** 67-74.

Berglund, B., Hassmen, P. & Job, R. S. 1996. Sources and effects of low-frequency noise. *The Journal of the Acoustical Society of America,* 99**,** 2985-3002.

Berglund, L. Mathematical models for predicting thermal comfort response of building occupants. Ashrae Journal-American Society of Heating Refrigerating and Air-Conditioning Engineers, 1977. AMER SOC HEAT

REFRIG AIR-CONDITIONING ENG INC 1791 TULLIE CIRCLE NE, ATLANTA, GA 30329, 38-38.

Bernstein, J. A., Alexis, N., Bacchus, H., Bernstein, I. L., Fritz, P., Horner, E., Li, N., Mason, S., Nel, A., Oullette, J., Reijula, K., Reponen, T., Seltzer, J., Smith, A. & Tarlo, S. M. 2008. The health effects of nonindustrial indoor air pollution. *Journal of Allergy and Clinical Immunology,* 121**,** 585-591.

Beute, F. & de Kort, Y. A. 2018. The natural context of wellbeing: Ecological momentary assessment of the influence of nature and daylight on affect and stress for individuals with depression levels varying from none to clinical. *Health & place,* 49**,** 7-18.

Bielefeld, B. 2018. *Basics Office Design*, Birkhäuser.

Bluyssen, P. M. 2004. Sensory evaluation of indoor air pollution sources. *Air Pollution.* Springer.

Bluyssen, P. M. 2014. *The Healthy Indoor Environment: How to Assess Occupants' Well-Being in Buildings*.

Bluyssen, P. M., Aries, M. & van Dommelen, P. 2011. Comfort of workers in office buildings: The European HOPE project. *Building and Environment,* 46**,** 280-288.

Bluyssen, P. M., De Oliveira Fernandes, E., Groes, L., Clausen, G., Fanger, P. O., Valbjørn, O., Bernhard, C. A. & Roulet, C. A. 1996. European Indoor Air Quality Audit Project in 56 Office Buildings. *Indoor Air,* 6**,** 221-238.

Boerstra, A. C., Kulve, M. t., Toftum, J., Loomans, M. G. L. C., Olesen, B. W. & Hensen, J. L. M. 2015. Comfort and performance impact of personal control over thermal environment in summer: Results from a laboratory study. *Building and Environment,* 87**,** 315-326.

Bordass, B., Bromley, K. & Leaman, A. User and occupant controls in office buildings. International conference on building design, technology and occupant well-being in temperate climates, Brussels, Belgium, 1993. 12-5.

Bordass, B., Cohen, R., Standeven, M. & Leaman, A. 2001. Assessing building performance in use 2: technical performance of the Probe buildings. *Building Research & Information,* 29**,** 103-113.

Borin, M. & Monteiro, C. 2018. A case study on Irrelevant Speech Effect assessment at open plan offices using Equivalent Modulation.

Box, G. E. & Draper, N. R. 1987. *Empirical model-building and response surfaces*, Wiley New York.

Boyce, P. & Association, N. E. M. 2001. *Lighting and human performance II: Beyond visibility models toward a unified human factors approach to performance*, National Electrical Manufacturers Association.

Boyce, P., Hunter, C. & Howlett, O. 2003. The benefits of daylight through windows. *Troy, New York: Rensselaer Polytechnic Institute*.

Brager, G. & Baker, L. 2009. Occupant satisfaction in mixed-mode buildings. *Building Research & Information,* 37**,** 369-380.

Brager, G. S. & de Dear, R. J. 1998. Thermal adaptation in the built environment: a literature review. *Energy and Buildings,* 27**,** 83-96.

Brasche, S. & Bischof, W. 2005. Daily time spent indoors in German homes – Baseline data for the assessment of indoor exposure of German

occupants. *International Journal of Hygiene and Environmental Health,* 208, 247-253.
Brenner, P. & Cornell, P. 1994. The balance between privacy and collaboration in knowledge worker teams. *Human Factors in Organizational Design and Management., Stockholm, Sweden*.
Bright, G. T. 2012. The economics of Biophilia. *Why designing with nature in mind makes financial sense. New York (NY): Terrapin Bright Green*.
Brill, M., Margulis, S. T. & Konar, E. 1985. *Using office design to increase productivity*, Workplace Design and Productivity, Inc.
Bronzaft, A. L. 2000. Noise: Combating a ubiquitous and hazardous pollutant. *Noise and Health,* 2, 1.
Bryman, A. 2016. *Social research methods*, Oxford university press.
Busch, J. F., Du Pont, P. & Chirarattananon, S. 1993. Energy-efficient lighting in Thai commercial buildings. *Energy,* 18, 197-210.
Butler, D. L. & Biner, P. M. 1989. Effects of setting on window preferences and factors associated with those preferences. *Environment and Behavior,* 21, 17-31.
CABE 2005. The impact of Office Design on Business Performance. London: Commission for Architecture & Built Environment and the British Council for Offices.
Candas, V. & Dufour, A. 2005. Thermal comfort: multisensory interactions? *Journal of physiological anthropology and applied human science,* 24, 33-36.
Cao, B., Ouyang, Q., Zhu, Y., Huang, L., Hu, H. & Deng, G. 2012. Development of a multivariate regression model for overall satisfaction in public buildings based on field studies in Beijing and Shanghai. *Building and Environment,* 47, 394-399.
Cena, K. & de Dear, R. 2001. Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate. *Journal of Thermal Biology,* 26, 409-414.
Chang, S. & Mahdavi, A. 2002. A hybrid system for daylight responsive lighting control. *Journal of the Illuminating Engineering Society,* 31, 147-157.
Chang, T.-Y., Jain, R.-M., Wang, C.-S. & Chan, C.-C. 2003. Effects of occupational noise exposure on blood pressure. *Journal of occupational and environmental medicine,* 45, 1289-1296.
Charles, K. E. 2003. Fanger's thermal comfort and draught models.
Charmaz, K. 2006. *Constructing grounded theory: A practical guide through qualitative analysis*, Sage.
Choi, J., Aziz, A. & Loftness, V. Decision support for improving occupant environmental satisfaction in office buildings: The relationship between sub-set of IEQ satisfaction and overall environmental satisfaction. Proceedings of the 9th International Conference Healthy Buildings, Syracuse, NY USA, 2009.
CIBSE. 2015. *The CIBSE Journal CPD Programme: Lighting control technologies and strategies to cut energy consumption* [Online]. CIBSE. [Accessed 12/07/15 2015].

Clements-Croome, D. 2006. *Creating the productive workplace*, Taylor & Francis.
Clements-Croome, D. 2015. Creative and productive workplaces: a review. *Intelligent Buildings International*, 1-20.
Clements-Croome, D. J. 2000. *Creating the Productive Workplace*.
Clements-Croome, D. J. 2004. *Intelligent Buildings: Design, Management & Operation*.
Coghlan, D. 2019. *Doing action research in your own organization*, SAGE Publications Limited.
Collinge, W. O., Landis, A. E., Jones, A. K., Schaefer, L. A. & Bilec, M. M. 2014. Productivity metrics in dynamic LCA for whole buildings: Using a post-occupancy evaluation of energy and indoor environmental quality tradeoffs. *Building and Environment,* 82, 339-348.
Collins, K., Exton-Smith, A. & Dore, C. 1981. Urban hypothermia: preferred temperature and thermal perception in old age. *Br Med J (Clin Res Ed),* 282, 175-177.
Corbin, J., Strauss, A. & Strauss, A. L. 2014. *Basics of qualitative research*, sage.
Creswell, J. W. & Creswell, J. D. 2017. *Research design: Qualitative, quantitative, and mixed methods approaches*, Sage publications.
Cuttle, C. People and windows in workplaces. Proceedings of the people and physical environment research conference, 1983. 47-51.
De Been, I. & Beijer, M. 2014. The influence of office type on satisfaction and perceived productivity support. *Journal of Facilities Management,* 12, 142-157.
De Dear, R., Akimoto, T., Arens, E., Brager, G., Candido, C., Cheong, K., Li, B., Nishihara, N., Sekhar, S. & Tanabe, S. 2013. Progress in thermal comfort research over the last twenty years. *Indoor air,* 23, 442-461.
de Dear, R., Brager, G. & Cooper, D. 1997. *Developing an Adaptive Model of Thermal Comfort and Preference*.
De Dear, R. & Brager, G. S. 1998. Developing an adaptive model of thermal comfort and preference.
De Dear, R. J. & Brager, G. S. 2002. Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. *Energy and buildings,* 34, 549-561.
De Vecchi, R., Candido, C., de Dear, R. & Lamberts, R. 2017. Thermal comfort in office buildings: Findings from a field study in mixed-mode and fully-air conditioning environments under humid subtropical conditions. *Building and Environment,* 123, 672-683.
Deccio, C. & Baloglu, S. 2002. Nonhost community resident reactions to the 2002 Winter Olympics: The spillover impacts. *Journal of travel research,* 41, 46-56.
Del Ferraro, S., Iavicoli, S., Russo, S. & Molinaro, V. 2015. A field study on thermal comfort in an Italian hospital considering differences in gender and age. *Applied ergonomics,* 50, 177-184.
Deuble, M. P. & de Dear, R. J. 2012. Green occupants for green buildings: The missing link? *Building and Environment,* 56, 21-27.

DiLaura, D. L., Houser, K. W., Mistrick, R. G. & Steffy, G. R. 2011. *The lighting handbook: Reference and application*, Illuminating Engineering Society of North America New York.
Djongyang, N., Tchinda, R. & Njomo, D. 2010. Thermal comfort: A review paper. *Renewable and Sustainable Energy Reviews,* 14**,** 2626-2640.
Doulos, L., Tsangrassoulis, A. & Topalis, F. A critical review of simulation techniques for daylight responsive systems. Proceedings of the European Conference on Dynamic Analysis, Simulation and Testing applied to the Energy and Environmental performance of Buildings DYNASTEE, 2005.
Dufton, A. 1929. The eupatheostat. *Journal of scientific instruments,* 6**,** 249.
Dufton, A. 1930. LXXIX. The effective temperature of a warmed room. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science,* 9**,** 858-861.
Dykes, C. & Baird, G. 2013. A review of questionnaire-based methods used for assessing and benchmarking indoor environmental quality. *Intelligent Buildings International,* 5**,** 135-149.
Economides, M. J. & Wood, D. A. 2009. The state of natural gas. *Journal of Natural Gas Science and Engineering,* 1**,** 1-13.
Edwards, L. & Torcellini, P. A. 2002. *A literature review of the effects of natural light on building occupants*, National Renewable Energy Laboratory Golden, CO.
Eisenhardt, K. M. & Graebner, M. E. 2007. Theory building from cases: Opportunities and challenges. *Academy of management journal,* 50**,** 25-32.
El Mallakh, R. 2015. *Qatar (RLE Economy of Middle East): Development of an Oil Economy*, Routledge.
Elzeyadi, I. M. 2011. Daylighting-Bias and Biophilia: Quantifying the Impact of Daylighting on Occupants Health. *US Green Building Council. http://www. usgbc. org/sites/default/files/OR10_Daylighting% 20Bias% 20and% 20Biophilia. pdf*.
Eriksson, H. P., Andersson, E., Schiöler, L., Söderberg, M., Sjöström, M., Rosengren, A. & Torén, K. 2018. Longitudinal study of occupational noise exposure and joint effects with job strain and risk for coronary heart disease and stroke in Swedish men. *BMJ open,* 8**,** e019160.
Evans, G. W. & Lepore, S. J. 1993. Nonauditory effects of noise on children: A critical review. *Children's environments***,** 31-51.
Ezzeldin, S. & Rees, S. J. 2013. The potential for office buildings with mixed-mode ventilation and low energy cooling systems in arid climates. *Energy and Buildings,* 65**,** 368-381.
Fanger, P. 1984. Moderate Thermal Environments Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort. *ISO 7730*.
Fanger, P. 2000. Indoor air quality in the 21st century: search for excellence. *Indoor air,* 10**,** 68-73.
Fanger, P. O. 1970. *Thermal Comfort*.

Fanger, P. O. 1988. Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors. *Energy and Buildings,* 12, 1-6.
Farkas, T. 1985. *Daylighting in office buildings.* University of British Columbia.
Fay, C., Rea, M. & Figueiro, M. 2002. Daylighting and Productivity A Literature Review. *Lighting Research Center, Rensselaer Polytechnic Institute, Report of Project" Cross-Cutting R&D on Adaptive Full-Spectrum Solar Energy Systems for More Efficient and Affordable Use of Solar Energy in Buildings and Hybrid Photo-Bioreactors" sponsored by US Department of Energy*.
Feige, A., Wallbaum, H., Janser, M. & Windlinger, L. 2013. Impact of sustainable office buildings on occupant's comfort and productivity. *Journal of Corporate Real Estate,* 15, 7-34.
Field, C. 2008. Acoustic design in green buildings. *Ashrae Journal,* 50, 60-70.
Fisk, W. J. 2000a. Estimates of potential nationwide productivity and health benefits from better indoor environments: an update. *Indoor air quality handbook,* 4.
Fisk, W. J. 2000b. Health and productivity gains from better indoor environments and their relationship with building energy efficiency. *Annual Review of Energy and the Environment,* 25, 537-566.
Fisk, W. J., Black, D. & Brunner, G. 2012. Changing ventilation rates in US offices: Implications for health, work performance, energy, and associated economics. *Building and Environment,* 47, 368-372.
Fisk, W. J., Mendell, M. J., Daisey, J. M., Faulkner, D., Hodgson, A. T., Nematollahi, M. & Macher, J. M. 1993. Phase 1 of the California Healthy Building Study: A Summary. *Indoor Air,* 3, 246-254.
Fisk, W. J., Spengler, J. D., Samet, J. M. & McCarthy, J. F. 1999. *Indoor Air Quality Handbook*.
Fleming, D. 2004. Facilities management: a behavioural approach. *Facilities,* 22, 35-43.
Fontoynont, M. 2014. *Daylight performance of buildings*, Routledge.
Foucault, M. 2018. Discipline. *Rethinking The Subject.* Routledge.
Fredline, L., Jago, L. & Deery, M. 2003. The development of a generic scale to measure the social impacts of events. *Event management,* 8, 23-37.
Freire, R. Z., Oliveira, G. H. & Mendes, N. 2008. Predictive controllers for thermal comfort optimization and energy savings. *Energy and buildings,* 40, 1353-1365.
Frontczak, M., Schiavon, S., Goins, J., Arens, E. A., Zhang, H. P. D. & Wargocki, P. 2012. Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design.
Frontczak, M. & Wargocki, P. 2011. Literature survey on how different factors influence human comfort in indoor environments. *Building and Environment,* 46, 922-937.
Fuks, K. B., Weinmayr, G., Basagaña, X., Gruzieva, O., Hampel, R., Oftedal, B., Sørensen, M., Wolf, K., Aamodt, G. & Aasvang, G. M. 2017. Long-term exposure to ambient air pollution and traffic noise and incident

hypertension in seven cohorts of the European study of cohorts for air pollution effects (ESCAPE). *European heart journal,* 38, 983-990.
Gabay, H., Meir, I. A., Schwartz, M. & Werzberger, E. 2014. Cost-benefit analysis of green buildings: An Israeli office buildings case study. *Energy and Buildings,* 76, 558-564.
Gagge, A. P., Burton, A. C. & Bazett, H. C. 1941. A practical system of units for the description of the heat exchange of man with his environment. *Science,* 94, 428-430.
Glaser, B. G. & Strauss, A. L. 1967. The discovery ofgrounded theory: Strategiesfor qualitative research. *Chicago: Aldire*.
Göçer, Ö., Hua, Y. & Göçer, K. 2015. Completing the missing link in building design process: Enhancing post-occupancy evaluation method for effective feedback for building performance. *Building and Environment,* 89, 14-27.
Godish, T. & Spengler, J. D. 1996. Relationships between ventilation and indoor air quality: a review. *Indoor Air,* 6, 135-145.
Goldman, R. F. 1999. Extrapolating ASHRAE's comfort model. *HVAC&R Research,* 5, 189-194.
Gou, Z., Prasad, D. & Lau, S. S.-Y. 2014. Impacts of green certifications, ventilation and office types on occupant satisfaction with indoor environmental quality. *Architectural Science Review,* 57, 196-206.
Grinde, B. & Patil, G. G. 2009. Biophilia: does visual contact with nature impact on health and well-being? *International Journal of Environmental Research and Public Health,* 6, 2332-2343.
GSAS/QSAS 2012. GSAS/QSAS Technical Guide, Version 1.0. Gulf Organisation for Research and Development Doha, Qatar.
Gunderson, E., Moline, J. & Catalano, P. 1997. Risks of developing noise-induced hearing loss in employees of urban music clubs. *American journal of industrial medicine,* 31, 75-79.
Guzowski, M. 2000. *Daylighting for sustainable design*, McGraw-Hill Professional Publishing.
Haans, A. 2014. The natural preference in people's appraisal of light. *Journal of Environmental Psychology,* 39, 51-61.
Hakim, C. 2012. *Research Design: Succesful Designs for Social Economics Research*, Routledge.
Hammersley, M. & Atkinson, P. 2007. *Ethnography: Principles in practice*, Routledge.
Han, J., Zhang, G., Zhang, Q., Zhang, J., Liu, J., Tian, L., Zheng, C., Hao, J., Lin, J. & Liu, Y. 2007. Field study on occupants' thermal comfort and residential thermal environment in a hot-humid climate of China. *Building and Environment,* 42, 4043-4050.
Hassanain, M. A. 2007. Post-occupancy indoor environmental quality evaluation of student housing facilities. *Architectural Engineering and Design Management,* 3, 249-256.
Haynes, B. P. 2007a. The impact of the behavioural environment on office productivity. *Journal of Facilities Management,* 5, 158-171.

Haynes, B. P. 2007b. Office productivity: a theoretical framework. *Journal of Corporate Real Estate,* 9, 97-110.
Haynes, B. P. 2008a. An evaluation of the impact of the office environment on productivity. *Facilities,* 26, 178-195.
Haynes, B. P. 2008b. The impact of office layout on productivity. *Journal of Facilities Management,* 6, 189-201.
Haynes, B. P. 2009. Research design for the measurement of perceived office productivity. *Intelligent Buildings International,* 1, 169-183.
Heerwagen, J. H. 2003. Bio-inspired design: What can we learn from nature. *Unpublished manuscript*.
Heerwagen, J. H., Kampschroer, K., Powell, K. M. & Loftness, V. 2004. Collaborative knowledge work environments. *Building research & information,* 32, 510-528.
Heinrich, J. 2011. Influence of indoor factors in dwellings on the development of childhood asthma. *International Journal of Hygiene and Environmental Health,* 214, 1-25.
Hensen, J. L. M. 1991. *On the thermal interaction of building structure and heating and ventilating system*, Technische Universiteitt Eindhoven.
Herzberg, F. 1966. *Work and the Nature of Man*.
Heschong, L. 1979. *Thermal Delight in Architecture*.
Hicks, C. R. 1964. Fundamental concepts in the design of experiments.
Hill, W. J. & Hunter, W. G. 1966. A review of response surface methodology: a literature survey. *Technometrics,* 8, 571-590.
Hockman, K. K. & Berengut, D. 1995. Design of experiments. *Chemical Engineering,* 102, 142.
Hodgson, M. 2000. Sick building syndrome. *Occupational medicine (Philadelphia, Pa.),* 15, 571.
Hopkinson, R. G. 1963. Architectural Physics: Lighting.
Hopkinson, R. G., Petherbridge, P. & Longmore, J. 1966. *Daylighting*, Heinemann.
Huang, L., Zhu, Y., Ouyang, Q. & Cao, B. 2012. A study on the effects of thermal, luminous, and acoustic environments on indoor environmental comfort in offices. *Building and Environment,* 49, 304-309.
Humphreys, M. 1978. Outdoor temperatures and comfort indoors. *Batiment International, Building Research and Practice,* 6, 92-92.
Indraganti, M. & Boussaa, D. 2017. Comfort temperature and occupant adaptive behavior in offices in Qatar during summer. *Energy and Buildings,* 150, 23-36.
Indraganti, M. & Boussaa, D. 2018. An adaptive relationship of thermal comfort for the Gulf Cooperation Council (GCC) Countries: The case of offices in Qatar. *Energy and Buildings,* 159, 201-212.
Indraganti, M., Ooka, R. & Rijal, H. B. 2015. Thermal comfort in offices in India: Behavioral adaptation and the effect of age and gender. *Energy and Buildings,* 103, 284-295.
Indraganti, M. & Rao, K. D. 2010. Effect of age, gender, economic group and tenure on thermal comfort: A field study in residential buildings in hot

and dry climate with seasonal variations. *Energy and Buildings,* 42, 273-281.

Ising, H. & Kruppa, B. 2004. Health effects caused by noise: evidence in the literature from the past 25 years. *Noise and Health,* 6, 5.

Jaffal, A., Banat, I., El Mogheth, A., Nsanze, H., Bener, A. & Ameen, A. 1997. Residential indoor airborne microbial populations in the United Arab Emirates. *Environment International,* 23, 529-533.

Jahncke, H. & Halin, N. 2012. Performance, fatigue and stress in open-plan offices: The effects of noise and restoration on hearing impaired and normal hearing individuals. *Noise and Health,* 14, 260.

Jakobsen, J. 2003. Danish guidelines on environmental low frequency noise, infrasound and vibration. *noise notes,* 2, 10-18.

Jaradat, Q. M., Momani, K. A., Jbarah, A.-A. Q. & Massadeh, A. 2004. Inorganic analysis of dust fall and office dust in an industrial area of Jordan. *Environmental research,* 96, 139-144.

Javid, A., Hamedian, A. A., Gharibi, H. & Sowlat, M. H. 2016. Towards the Application of Fuzzy Logic for Developing a Novel Indoor Air Quality Index (FIAQI). *Iranian Journal of Public Health,* 45, 203-213.

Jiju, A. 2003. A systematic methodology for design of experiments. *Design of experiments for engineers and scientists, Elsevier Press, Oxford, UK*, 29-41.

Jin, X., Wang, G., Song, Y. & Sun, C. 2018. Smart building energy management based on network occupancy sensing. *Journal of International Council on Electrical Engineering,* 8, 30-36.

Jones, A. P. 1999. Indoor air quality and health. *Atmospheric Environment,* 33, 4535-4564.

Jones, C. 2001. Mega-events and host-region impacts: determining the true worth of the 1999 Rugby World Cup. *International Journal of Tourism Research,* 3, 241-251.

Kallio, T. J., Kallio, K.-M. & Blomberg, A. J. 2015. Physical space, culture and organisational creativity – a longitudinal study. *Facilities,* 33, 389-411.

Kaplanidou, K., Al Emadi, A., Sagas, M., Diop, A. & Fritz, G. 2016. Business legacy planning for mega events: The case of the 2022 World Cup in Qatar. *Journal of Business Research,* 69, 4103-4111.

Karadakis, K. & Kaplanidou, K. 2012. Legacy perceptions among host and non-host Olympic Games residents: A longitudinal study of the 2010 Vancouver Olympic Games. *European Sport Management Quarterly,* 12, 243-264.

Karamata, B. & Andersen, M. Concept, Design and Performance of a Shape Variable Mashrabiya as a Shading and Daylighting System for Arid Climates. 30th PLEA Conference-SUSTAINABLE HABITAT FOR DEVELOPING SOCIETIES, 2014. CEPT University Ahmedabad, 344-351.

Karjalainen, S. 2012. Thermal comfort and gender: a literature review. *Indoor Air,* 22, 96-109.

Kekäläinen, P., Niemelä, R., Tuomainen, M., Kemppilä, S., Palonen, J., Riuttala, H., Nykyri, E., Seppänen, O. & Reijula, K. 2010. Effect of reduced summer indoor temperature on symptoms, perceived work environment and

productivity in office work: An intervention study. *Intelligent Buildings International,* 2, 251-266.
Kelemen, M. L. & Rumens, N. 2008. *An introduction to critical management research*, Sage.
Kim, J. & de Dear, R. 2012. Impact of different building ventilation modes on occupant expectations of the main IEQ factors. *Building and Environment,* 57, 184-193.
Kim, J. & de Dear, R. 2013. Workspace satisfaction: The privacy-communication trade-off in open-plan offices. *Journal of Environmental Psychology,* 36, 18-26.
Kim, J., de Dear, R., Cândido, C., Zhang, H. & Arens, E. 2013. Gender differences in office occupant perception of indoor environmental quality (IEQ). *Building and Environment,* 70, 245-256.
Kittler, R., Hayman, S., Ruck, N. & Julian, W. 1992. Daylight measurement data: Methods of evaluation and representation. *Lighting Research & Technology,* 24, 173-187.
Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., Behar, J. V., Hern, S. C. & Engelmann, W. H. 2001. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *J Expo Anal Environ Epidemiol,* 11, 231-52.
Kong, Z., Utzinger, D. M., Freihoefer, K. & Steege, T. 2018. The impact of interior design on visual discomfort reduction: a field study integrating lighting environments with POE survey. *Building and Environment,* 138, 135-148.
Korte, C. & Grant, R. 1980. Traffic noise, environmental awareness, and pedestrian behavior. *Environment and Behavior,* 12, 408-420.
Kosonen, R. & Tan, F. 2004. The effect of perceived indoor air quality on productivity loss. *Energy and Buildings,* 36, 981-986.
Kotler, P., Armstrong, G., Brown, L. & Adam, S. 2006. Marketing. Australia: Pearson Education Australia. Prentice Hall.
L Edwards, P. T. 2000. A literature review of the effects of natural light on building occupants.
Laing, A., Duffy, F., Jaunzens, D. & Willis, S. 1998. *New Environments for Working: The Re-Design of Offices and Environmental Systems for New Ways of Working,* London, Construction Research Communications.
Lan, L., Lian, Z. & Pan, L. 2010. The effects of air temperature on office workers' well-being, workload and productivity-evaluated with subjective ratings. *Applied ergonomics,* 42, 29-36.
Lan, L., Wargocki, P. & Lian, Z. 2011. Quantitative measurement of productivity loss due to thermal discomfort. *Energy and Buildings,* 43, 1057-1062.
Langer, S. & Bekö, G. 2013. Indoor air quality in the Swedish housing stock and its dependence on building characteristics. *Building and Environment,* 69, 44-54.
Langer, S., Ramalho, O., Derbez, M., Ribéron, J., Kirchner, S. & Mandin, C. 2016. Indoor environmental quality in French dwellings and building characteristics. *Atmospheric Environment,* 128, 82-91.

Langevin, J., Gurian, P. L. & Wen, J. 2015. Tracking the human-building interaction: A longitudinal field study of occupant behavior in air-conditioned offices. *Journal of Environmental Psychology,* 42**,** 94-115.

Langevin, J., Wen, J. & Gurian, P. L. 2013. Modeling thermal comfort holistically: Bayesian estimation of thermal sensation, acceptability, and preference distributions for office building occupants. *Building and Environment,* 69**,** 206-226.

Leaman, A. & Bordass, B. 1999. Productivity in buildings: the 'killer' variables. *Building Research & Information,* 27**,** 4-19.

Leaman, A. & Bordass, B. 2001. Assessing building performance in use 4: the Probe occupant surveys and their implications. *Building Research & Information,* 29**,** 129-143.

Lee, C.-K., Lee, Y.-K. & Lee, B. 2005. Korea's destination image formed by the 2002 World Cup. *Annals of tourism research,* 32**,** 839-858.

Lee, C. S. & Fleming, G. G. 2002. General Health effects of transportation noise. *US Department of Transportation: Washington, DC*.

Lee, Y. S. 2010. Office layout affecting privacy, interaction, and acoustic quality in LEED-certified buildings. *Building and Environment,* 45**,** 1594-1600.

Lee, Y. S. & Guerin, D. A. 2009. Indoor environmental quality related to occupant satisfaction and performance in LEED-certified buildings. *Indoor and Built Environment,* 18**,** 293-300.

Lewis, P., Thornhill, A. & Saunders, M. 2007. *Research methods for business students*, Pearson Education UK.

Lewis, S. 2015. Qualitative inquiry and research design: Choosing among five approaches. *Health promotion practice,* 16**,** 473-475.

Li, D. H. W. & Lam, J. C. 2001. Evaluation of lighting performance in office buildings with daylighting controls. *Energy and Buildings,* 33**,** 793-803.

Li, D. H. W. & Tsang, E. K. W. 2008. An analysis of daylighting performance for office buildings in Hong Kong. *Building and Environment,* 43**,** 1446-1458.

Lim, G.-H., Hirning, M. B., Keumala, N. & Ghafar, N. A. 2017. Daylight performance and users' visual appraisal for green building offices in Malaysia. *Energy and Buildings,* 141**,** 175-185.

Lin, Z. & Deng, S. 2008. A study on the thermal comfort in sleeping environments in the subtropics—Developing a thermal comfort model for sleeping environments. *Building and Environment,* 43**,** 70-81.

Lipczynska, A., Schiavon, S. & Graham, L. T. 2018. Thermal comfort and self-reported productivity in an office with ceiling fans in the tropics. *Building and Environment,* 135**,** 202-212.

Lorsch, H. G. & Abdou, O. A. 1994. The impact of the building indoor environment on occupant productivity--part 1: recent studies, measures, and costs. *ASHRAE Transactions-American Society of Heating Refrigerating Airconditioning Engin,* 100**,** 741-749.

Lottrup, L., Stigsdotter, U. K., Meilby, H. & Claudi, A. G. 2015. The workplace window view: a determinant of office workers' work ability and job satisfaction. *Landscape Research,* 40**,** 57-75.

Lyons, P., Arasteh, D. & Huizenga, C. 2000. Window performance for human thermal comfort. *TRANSACTIONS-AMERICAN SOCIETY OF HEATING REFRIGERATING AND AIR CONDITIONING ENGINEERS,* 106, 594-604.

MacKerron, G. & Mourato, S. 2013. Happiness is greater in natural environments. *Global Environmental Change,* 23, 992-1000.

Macpherson, R. 1962. The assessment of the thermal environment. A review. *British journal of industrial medicine,* 19, 151-164.

Macpherson, R. 1973. Thermal stress and thermal comfort. *Ergonomics,* 16, 611-622.

Mahgoub, Y. & Abbara, B. 2012. Tall Buildings Legislations in Doha, Qatar. *Procedia - Social and Behavioral Sciences,* 36, 640-649.

Manning, M. A. 2006. An Experimental Evaluation and Comparison of Four Daylighting Strategies for Schools in North Carolina.

Mansfield, K. 2018. Architectural lighting design: A research review over 50 years. *Lighting Research & Technology,* 50, 80-97.

Marans, R. W. & Yan, X.-y. 1989. LIGHTING QUALITY AND ENVIRONMENTAL SATISFACTION IN OPEN AND ENCLOSED OFFICES. *Journal of Architectural and Planning Research,* 6, 118-131.

Maslow, A. H. 1943. A theory of human motivation. *Psychological review,* 50, 370.

Mason, A. & Lee, R. 2007. Transfers, capital, and consumption over the demographic transition. *Population aging, intergenerational transfers and the macroeconomy*, 128-162.

McCunn, L. J., Kim, A. & Feracor, J. 2018. Reflections on a retrofit: Organizational commitment, perceived productivity and controllability in a building lighting project in the United States. *Energy Research & Social Science,* 38, 154-164.

Meyer, D. L. 1963. Response surface methodology in education and psychology. *The Journal of Experimental Education,* 31, 329-336.

Miller, N. G., Pogue, D., Gough, Q. D. & Davis, S. M. 2009. Green Building and Productivity. *Journal of Sustainable Real Estate,* 1, 65.

Millward, P. 2017. World Cup 2022 and Qatar's construction projects: Relational power in networks and relational responsibilities to migrant workers. *Current Sociology,* 65, 756-776.

Montgomery, D. C. & Myers, R. H. 1995. Response surface methodology: process and product optimization using designed experiments. *Raymond H. Meyers and Douglas C. Montgomery. A Wiley-Interscience Publications*.

Montgomery, D. C., Runger, G. C. & Hubele, N. F. 2009. *Engineering statistics*, John Wiley & Sons.

Mostavi, E., Asadi, S. & Boussaa, D. 2017. Development of a new methodology to optimize building life cycle cost, environmental impacts, and occupant satisfaction. *Energy,* 121, 606-615.

Mui, K. & Wong, L. 2006. A method of assessing the acceptability of noise levels in air-conditioned offices. *Building Services Engineering Research and Technology,* 27, 249-254.

Myers, R. H., Montgomery, D. C. & Anderson-Cook, C. M. 2016. *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*, John Wiley & Sons.
Nagelkerke, N. J. 1991. A note on a general definition of the coefficient of determination. *Biometrika,* 78, 691-692.
Nagy, E., Yasunaga, S. & Kose, S. 1995. Japanese office employees' psychological reactions to their underground and above-ground offices. *Journal of environmental psychology,* 15, 123-134.
Ne'Eman, E. 1970. Critical minimum acceptable window size: a study of window design and provision of a view.
Neitzel, R., Roberts, B., Sayler, S., Cheng, W. & Mukherjee, B. 2018. Progress in assessing and limiting occupational noise exposures in the United States. *The Journal of the Acoustical Society of America,* 143, 1780-1780.
Ng, L. C., Musser, A., Persily, A. K. & Emmerich, S. J. 2012. Indoor air quality analyses of commercial reference buildings. *Building and Environment,* 58, 179-187.
Nicol, F., Humphreys, M. & Roaf, S. 2012. *Adaptive Thermal Comfort: Principles and Practice*.
Nicol, F. & Roaf, S. 2005. Post-occupancy evaluation and field studies of thermal comfort. *Building Research & Information,* 33, 338-346.
Ogbonna, A. C. & Harris, D. J. 2008. Thermal comfort in sub-Saharan Africa: Field study report in Jos-Nigeria. *Applied Energy,* 85, 1-11.
Olesen, B. W. & Parsons, K. C. 2002. Introduction to thermal comfort standards and to the proposed new version of EN ISO 7730. *Energy and Buildings,* 34, 537-548.
Omer, A. M. 2008. Energy, environment and sustainable development. *Renewable and Sustainable Energy Reviews,* 12, 2265-2300.
Oseland, N. 1999. *Environmental Factors Affecting Office Worker Performance: A Review of Evidence,* London, CIBSE.
Oseland, N. 2004. Occupant feedback tools of the office productivity network. *Assessed http://www. officeproductivity. co. uk*.
Otterbring, T., Pareigis, J., Wästlund, E., Makrygiannis, A. & Lindström, A. 2018. The relationship between office type and job satisfaction: Testing a multiple mediation model through ease of interaction and well-being. *Scandinavian journal of work, environment & health,* 44, 330-334.
Ozturk, Z., Arayici, Y. & Coates, S. 2012. Post occupancy evaluation (POE) in residential buildings utilizing BIM and sensing devices: Salford energy house example.
Palmer, S. 2018. What is toxic childhood? *Childhood, Well-Being and a Therapeutic Ethos.* Routledge.
Panagiotaras, D., Nikolopoulos, D., Koulougliotis, D., Petraki, E., Zisos, I., Yiannopoulos, A., Bakalis, A. & Zisos, A. 2013. Indoor Air Quality Assessment: Review on the topic of VOCs.
Passchier-Vermeer, W. & Passchier, W. F. 2000. Noise exposure and public health. *Environmental health perspectives,* 108, 123.

Paul, W. L. & Taylor, P. A. 2008. A comparison of occupant comfort and satisfaction between a green building and a conventional building. *Building and Environment,* 43, 1858-1870.

Payne, S. R. 2013. The production of a perceived restorativeness soundscape scale. *Applied Acoustics,* 74, 255-263.

Pellerin, N. & Candas, V. 2004. Effects of steady-state noise and temperature conditions on environmental perception and acceptability. *Indoor air,* 14, 129-136.

Potbhare, V., Syal, M., Arif, M., Khalfan, M. M. & Egbu, C. 2009. Emergence of green building guidelines in developed countries and their impact on India. *Journal of Engineering, Design and Technology,* 7, 99-121.

Prasad, S. 2004. Clarifying intentions: the design quality indicator. *Building Research & Information,* 32, 548-551.

Preiser, W. F. 1995. Post-occupancy evaluation: how to make buildings work better. *Facilities,* 13, 19-28.

Preiser, W. F., White, E. & Rabinowitz, H. 2015. *Post-Occupancy Evaluation (Routledge Revivals)*, Routledge.

Quang, T. N., He, C., Knibbs, L. D., de Dear, R. & Morawska, L. 2014. Co-optimisation of indoor environmental quality and energy consumption within urban office buildings. *Energy and Buildings,* 85, 225-234.

Rasheed, E. O. & Byrd, H. 2018. Can a naturally ventilated office outperform a mixed mode office? Pilot study on occupants' comfort. *Building and Environment,* 137, 34-40.

Rea, M., Figueiro, M. & Bullough, J. 2002. Circadian photobiology: An emerging framework for lighting practice and research. *Lighting Research and Technology,* 34, 177-187.

Rea, M. S. 2000. The IESNA lighting handbook: reference & application.

Reason, P. & Bradbury, H. 2001. *Handbook of action research: Participative inquiry and practice*, Sage.

Reed, M. 2005. Reflections on the 'realist turn'in organization and management studies. *Journal of Management Studies,* 42, 1621-1644.

Reichertz, J. 2007. *Abduction: The logic of discovery of grounded theory*, Sage London.

Reinhart, C. F. Effects of interior design on the daylight availability in open plan offices. 2002 ACEEE Summer Study on Energy Efficiency in Buildings, 2002. 309-322.

Reinhart, C. F., Mardaljevic, J. & Rogers, Z. 2006. Dynamic daylight performance metrics for sustainable building design. *Leukos,* 3, 7-31.

Robson, C. 2002. *Real world research: A resource for social scientists and practitioner-researchers*, Blackwell Oxford.

Roelofsen, P. 2002. The impact of office environments on employee performance: The design of the workplace as a strategy for productivity enhancement. *Journal of Facilities Management,* 1, 247-264.

Roelofsen, P. 2015. A computer model for the assessment of employee performance loss as a function of thermal discomfort or degree of heat stress. *Intelligent Buildings International*, 1-20.

Rogerson, C. M. 2009. Mega-events and small enterprise development: the 2010 FIFA World Cup opportunities and challenges. *Development Southern Africa,* 26**,** 337-352.

Romm, J. & Browning, W. 1994. Greening the Building and the Bottom Line - Increasing productivity through energy-efficient design. Rocky Mountain Institute.

Rossi, P. H., Wright, J. D. & Anderson, A. B. 2013. *Handbook of survey research*, Academic Press.

Rubin, A., Collins, B. & Tibbott, R. 1978. Window blinds as potential energy saver–a case study, NBS Building Science Series, vol. 112. *National Institute for Standards and Technology, Gaithersburg, MA, USA*.

Salama, A. The impact of economic diversification on urban morphologies in Doha: an interdisciplinary assessment. Qatar Foundation Annual Research Conference, 2013. SSHP 017.

Salama, A. M. & Courtney, L. 2013. THE IMPACT OF THE SPATIAL QUALITIES OF THE WORKPLACE ON ARCHITECTS'JOB SATISFACTION. *International Journal of Architectural Research: ArchNet-IJAR,* 7**,** 52-64.

Saraga, D., Maggos, T., Sadoun, E., Fthenou, E., Hassan, H., Tsiouri, V., Karavoltsos, S., Sakellari, A., Vasilakos, C. & Kakosimos, K. 2017. Chemical characterization of indoor and outdoor particulate matter (PM2. 5, PM10) in Doha, Qatar. *Aerosol and Air Quality Research,* 17**,** 1156-1168.

Saunders, M., Lewis, P. & Thornhill, A. 2012. *Research Methods for Business Students*, Pearson Education M.U.A.

Saunders, M., Lewis, P., Thornhill, A. & Bristow, A. 2019. *"Research Methods for Business Students" Chapter 4: Understanding research philosophy and approaches to theory development*.

Saunders, M. N., Saunders, M., Lewis, P. & Thornhill, A. 2011. *Research methods for business students, 5/e*, Pearson Education India.

Schaffner, M., Sarkar, J., Torgler, B. & Dulleck, U. 2018. The implications of daylight saving time: A quasi-natural experiment on cognitive performance and risk taking behaviour. *Economic Modelling,* 70**,** 390-400.

Sehar, F., Pipattanasomporn, M. & Rahman, S. 2017. Integrated automation for optimal demand management in commercial buildings considering occupant comfort. *Sustainable cities and society,* 28**,** 16-29.

Sekhar, S., Gong, N., Tham, K. W., Cheong, K., Melikov, A. K., Wyon, D. & Fanger, P. O. 2005. Findings of personalized ventilation studies in a hot and humid climate. *HVAC&R Research,* 11**,** 603-620.

Seppänen, O., Fisk, W. & Mendell, M. 1999. Association of ventilation rates and CO2 concentrations with health and other responses in commercial and institutional buildings. *Indoor air,* 9**,** 226-252.

Seppanen, O., Fisk, W. J. & Faulkner, D. 2003. Cost benefit analysis of the night-time ventilative cooling in office building. *Lawrence Berkeley National Laboratory*.

Seppanen, O., Fisk, W. J. & Lei, Q. 2006. Effect of temperature on task performance in office environment.

Seppänen, O. A. & Fisk, W. 2006. Some quantitative relations between indoor environmental quality and work performance or health. *Hvac&R Research,* 12**,** 957-973.

Sexton, M. A supple approach to exposing and challenging assumptions and PhD path dependencies in research. Key note speech of the 3rd international postgraduate research conference, 2003.

Shaharon, M. N. & Jalaludin, J. 2012. Thermal Comfort Assessment-A Study Toward Workersâ€™ Satisfaction in a Low Energy Office Building. *American Journal of Applied Sciences,* 9**,** 1037.

Shahzad, S., Brennan, J., Theodossopoulos, D., Hughes, B. & Calautit, J. K. Energy and comfort in contemporary open plan and traditional personal offices. *Applied Energy*.

Shahzad, S., Brennan, J., Theodossopoulos, D., Hughes, B. & Calautit, J. K. 2016. Energy and comfort in contemporary open plan and traditional personal offices. *Applied Energy*.

Shahzad, S., Calautit, J. K., Calautit, K., Hughes, B. & Aquino, A. I. 2018. Advanced Personal Comfort System (APCS) for the workplace: A review and case study. *Energy and Buildings*.

Shapiro, S. A. & Suter, A. H. The dormant noise control act and options to abate noise pollution. 1991. Administrative Conference of the United States.

Silva, M. F., Maas, S., de Souza, H. A. & Gomes, A. P. 2017. Post-occupancy evaluation of residential buildings in Luxembourg with centralized and decentralized ventilation systems, focusing on indoor air quality (IAQ). Assessment by questionnaires and physical measurements. *Energy and Buildings,* 148**,** 119-127.

Sivaji, A., Shopian, S., Nor, Z. M., Chuan, N.-K. & Bahri, S. 2013. Lighting does Matter: Preliminary Assessment on Office Workers. *Procedia - Social and Behavioral Sciences,* 97**,** 638-647.

Słomiński, S. & Krupiński, R. 2018. Luminance distribution projection method for reducing glare and solving object-floodlighting certification problems. *Building and Environment,* 134**,** 87-101.

Smith, R. B., Fecht, D., Gulliver, J., Beevers, S. D., Dajnak, D., Blangiardo, M., Ghosh, R. E., Hansell, A. L., Kelly, F. J. & Anderson, H. R. 2017. Impact of London's road traffic air and noise pollution on birth weight: retrospective population based cohort study. *bmj,* 359**,** j5299.

Stansfeld, S. A. & Matheson, M. P. 2003. Noise pollution: non-auditory effects on health. *British medical bulletin,* 68**,** 243-257.

Steffy, G. 2002. *Architectural lighting design*, John Wiley & Sons.

Stein, B., Reynolds, J. S. & McGuinness, W. J. 1992. *Mechanical and electrical equipment for buildings*, J. Wiley & Sons.

Stone, N. J. 2001. DESIGNING EFFECTIVE STUDY ENVIRONMENTS. *Journal of Environmental Psychology,* 21**,** 179-190.

Sundstrom, E., Town, J. P., Rice, R. W., Osborn, D. P. & Brill, M. 1994. Office noise, satisfaction, and performance. *Environment and Behavior,* 26**,** 195-222.

Szczurek, A., Maciejewska, M., Teuerle, M. & Wyłomańska, A. 2015. Method to characterize collective impact of factors on indoor air. *Physica A: Statistical Mechanics and its Applications,* 420**,** 190-199.

Tanabe, S.-i., Nishihara, N. & Haneda, M. 2007. Indoor Temperature, Productivity, and Fatigue in Office Tasks. *HVAC&R Research,* 13**,** 623-633.

Tarantini, M., Pernigotto, G. & Gasparella, A. 2017. A Co-Citation Analysis on Thermal Comfort and Productivity Aspects in Production and Office Buildings. *Buildings,* 7**,** 36.

Teichman, K. Y., Persily, A. K. & Emmerich, S. J. 2015. Indoor air quality in high-performing building case studies: Got data? *Science and Technology for the Built Environment,* 21**,** 91-98.

Telford, J. K. 2007. A brief introduction to design of experiments. *Johns Hopkins apl technical digest,* 27**,** 224-232.

Toftum, J., Lund, S., Kristiansen, J. & Clausen, G. Effect of open-plan office noise on occupant comfort and performance. 10th International Conference on Healthy Buildings, 2012.

Trochim, W. M. 2006. Units of analysis.

Tse, W. & So, A. T. 2007. The importance of human productivity to air-conditioning control in office environments. *HVAC&R Research,* 13**,** 3-21.

Tsushima, S., Tanabe, S.-i. & Utsumi, K. 2015. Workers' awareness and indoor environmental quality in electricity-saving offices. *Building and Environment,* 88**,** 10-19.

UKCMH 2011. Managing Presenteeism. www.centreformentalhealth.org.uk: UK Centre for Mental Health.

Van Den Wymelenberg, K. & Inanici, M. 2014. A critical investigation of common lighting design metrics for predicting human visual comfort in offices with daylight. *Leukos,* 10**,** 145-164.

Varun Potbhare, Matt Syal & Sinem Korkmaz 2009. Adoption of Green Building Guidelines in Developing Countries Based on U.S. and India Experiences. *Journal of Green Building,* 4**,** 158-174.

Veitch, J. A. 2001. Psychological processes influencing lighting quality. *Journal of the Illuminating Engineering Society,* 30**,** 124-140.

Vernon, H. M. & Bedford, T. 1926. A Physiological Study of the Ventilation and Heating in Certain Factories. *Medical Research Council. Indust. Fatigue Res. Board. Rep.*

Vernon, H. M. & Bedford, T. 1930. A Study of Heating and Ventilation in Schools. *Med. Res. Council, Indust. Health Res. Board (formerly Indust. Fatigue Res. Board) Rep.*

Vischer, J. C. 2007. The effects of the physical environment on job performance: towards a theoretical model of workspace stress. *Stress and Health: Journal of the International Society for the Investigation of Stress,* 23**,** 175-184.

Wang, Z., de Dear, R., Luo, M., Lin, B., He, Y., Ghahramani, A. & Zhu, Y. 2018. Individual difference in thermal comfort: A literature review. *Building and Environment*.

Wargocki, P. 2000. The ffects of outdoor air supply in an office on perceived air quality, sick building syndrome (SBS) symptoms and producivity. *Indoor air,* 10**,** 222-236.

Wargocki, P. 2017. Ventilation, indoor air quality, health, and productivity. *Ergonomic Workplace Design for Health, Wellness, and Productivity*. ROUTLEDGE in association with GSE Research.

Wargocki, P., Tham, K., Sekhar, S. & Cheong, D. Estimate of an economic benefit from investment in improved indoor air quality in an office building. 7th International Conference on Healthy Buildings 2003, 2003. 382-387.

Wargocki, P., Wyon, D. P., Baik, Y. K., Clausen, G. & Fanger, P. O. 1999. Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with two different pollution loads. *Indoor air,* 9**,** 165-179.

Wargocki, P., Wyon, D. P., Sundell, J., Clausen, G. & Fanger, P. 2000. The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity. *Indoor air,* 10**,** 222-236.

Wheeler, G. & Almeida, A. 2006. These Four Walls: The Real British Office. *Creating the Productive Workplace***,** 357.

WHO 2006. *Air quality guidelines: global update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide*, World Health Organization.

Williams, B. & Clements-Croome, D. J. 2006. *Creating the Productive Workplace*.

Winslow, C.-E. & Gagge, A. 1941. Influence of physical work on physiological reactions to the thermal environment. *American Journal of Physiology-Legacy Content,* 134**,** 664-681.

Wolkoff, P. 2013. Indoor air pollutants in office environments: assessment of comfort, health, and performance. *Int J Hyg Environ Health,* 216**,** 371-94.

Wolkoff, P. 2018. Indoor air humidity, air quality, and health–An overview. *International journal of hygiene and environmental health*.

Wolkoff, P. & Kjærgaard, S. K. 2007. The dichotomy of relative humidity on indoor air quality. *Environment International,* 33**,** 850-857.

Wong, L. 2017. A review of daylighting design and implementation in buildings. *Renewable and Sustainable Energy Reviews,* 74**,** 959-968.

Wong, N. H. & Khoo, S. S. 2003. Thermal comfort in classrooms in the tropics. *Energy and buildings,* 35**,** 337-351.

World Green Building Council 2014. Health, Wellbeing & Productivity in Offices. World Green Building Council.

Wotton, E. 1982. *An investigation of the effects of windows and lighting in offices*, Health and Welfare Canada.

Ximénez, M. C. & San Martín, R. 2000. Application of response surface methodology to the study of person-organization fit. *Psicothema,* 12**,** 151-158.

Yang, I.-H. & Nam, E.-J. 2010. Economic analysis of the daylight-linked lighting control system in office buildings. *Solar Energy,* 84**,** 1513-1525.

Yassin, M. F., AlThaqeb, B. E. & Al-Mutiri, E. A. 2012. Assessment of indoor PM2. 5 in different residential environments. *Atmospheric environment,* 56, 65-68.
Yeatts, K. B., El-Sadig, M., Leith, D., Kalsbeek, W., Al-Maskari, F., Couper, D., Funk, W. E., Zoubeidi, T., Chan, R. L. & Trent, C. B. 2012. Indoor air pollutants and health in the United Arab Emirates. *Environmental health perspectives,* 120, 687-694.
Yin, R. K. 2009. Case study research: Design and methods (applied social research methods). *London and Singapore: Sage*.
Yin, R. K. 2017. *Case study research and applications: Design and methods*, Sage publications.
Zagreus, L., Huizenga, C., Arens, E. & Lehrer, D. 2004. Listening to the occupants: a Web-based indoor environmental quality survey. *Indoor Air,* 14, 65-74.
Zhai, Y., Zhang, Y., Zhang, H., Pasut, W., Arens, E. & Meng, Q. 2015. Human comfort and perceived air quality in warm and humid environments with ceiling fans. *Building and Environment,* 90, 178-185.
Zhang, H., Arens, E., Kim, D., Buchberger, E., Bauman, F. & Huizenga, C. 2010. Comfort, perceived air quality, and work performance in a low-power task–ambient conditioning system. *Building and Environment,* 45, 29-39.
Zhang, H., Arens, E. & Pasut, W. 2011. Air temperature thresholds for indoor comfort and perceived air quality. *Building Research & Information,* 39, 134-144.
Zhang, Y. & Barrett, P. 2012. Factors influencing the occupants' window opening behaviour in a naturally ventilated office building. *Building and Environment,* 50, 125-134.
Zhao, Y., Uduku, O. & Murray-Rust, D. 2017. EdenApp Thermal Comfort: A mobile app for measuring personal thermal comfort.
Zheng, G., Jing, Y., Huang, H. & Ma, P. Thermal Comfort and Indoor Air Quality of Task Ambient Air Conditioning in Modern Office Buildings. Information Management, Innovation Management and Industrial Engineering, 2009 International Conference on, 2009. IEEE, 533-536.

8 Appendix

8.1 Appendix – 1 - Indoor Environment Quality Survey

1. How many years have you worked in this workplace?
    a. Less than 1 year
    b. 1-2 years
    c. 3-5 years
    d. More than 5 years
2. In a week, how many hours do you spend at your desk in the office (do not include field work)?
    a. Less than 30
    b. Between 30 – 40
    c. More than 40
3. How would you describe your job profile?
    a. Administrative support
    b. Technical
    c. Professional (GSAS/ Research)
    d. Managerial/supervisory
    e. Other
4. What is your age?
    a. Below 30
    b. 31 – 50
    c. Over 50
5. What is your gender?
    a. Female
    b. Male
6. What is your ethnicity?
    a. Caucasian
    b. South Asian
    c. Far East Asian

d. Middle Eastern
e. African
f. Other

7. What is your highest level of education?
    a. High school
    b. Bachelor degree
    c. Master degree
    d. Doctorate
    e. Other
8. How would you describe the terrain of the place you spent most of your time/ grew up?
    a. Forest/countryside
    b. Beach/Coastal
    c. Desert
    d. Mountains
    e. Inland
9. How have these factors affected your productivity in the past two weeks?

	Indoor environment factor	Very Negatively	Negatively	Neutral	Positively	Very Positively
A	Thermal comfort					
B	Natural ventilation					
C	Mechanical ventilation					
D	Low-emitting materials					
E	Illumination levels					
F	Daylight					
G	Indoor chemical & pollutant					

	source control					
H	Acoustic quality					
I	Office layout					

8.2 Appendix – 2 – PhD Schedule

	2015			2016				2017				2018			
Task	Apr - Jun	Jul - Sept	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sept	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sept	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sept	Oct - Dec
Learning Agreement	■														
Literature Review	■	■	■	■	■										
Aim, Objectives and Research Questions		■													
Research Methodology			■												
Synthesis of Research Material				■	■										
Interim Report Preperations					■	■	■								
Interim Assessment					■										
Ethical Approval					■										
Data Collection					■	■	■	■	■	■					
Internal Evaluation								■							
Data Assimilation and Analysis							■	■	■	■	■				
Develop Conclusion										■	■	■			
Write up Period											■	■	■	■	■
Final Thesis Submission and Defense															■

8.3 Appendix – 3 – Ethical Approval

University of Salford MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 5278

www.salford.ac.uk/

22 August 2016

Dear Amit,

RE: ETHICS APPLICATION ST16/109 – Occupant Productivity in office buildings: Indoor Environment Quality

Based on the information you provided, I am pleased to inform you that your application ST 16/109 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

Prof Mohammed Arif
Chair of the Science & Technology Research Ethics Panel
Professor of Sustainability and Process Management,
School of Built Environment
University of Salford
Maxwell Building, The Crescent
Greater Manchester, UK M5 4WT
Phone: + 44 161 295 6829
Email: m.arif@salford.ac.uk

8.4 Appendix – 4 – Response Surface Analysis – Backward Elimination Process (example)

Response Surface Regression: Thermal Comfort versus ... r (wall type):

The following terms cannot be estimated and were removed: Kind of Workspace*Do you sit near (wall type):

Backward Elimination of Terms

Candidate terms: Temperature, Relative Humidity, Outside temperature, Outside Relative Humidity, CO2, Sound, Light, VOC, Kind of Workspace, Do you sit near (wall type):, Temperature*Temperature, Relative Humidity*Relative Humidity, Outside temperature*Outside temperature, Outside Relative Humidity*Outside Relative Humidity, CO2*CO2, Sound*Sound, Light*Light, VOC*VOC, Temperature*Relative Humidity, Temperature*Outside temperature, Temperature*Outside Relative Humidity, Temperature*CO2, Temperature*Sound, Temperature*Light, Temperature*VOC, Temperature*Kind of Workspace, Temperature*Do you sit near (wall type):, Relative Humidity*Outside temperature, Relative Humidity*Outside Relative Humidity, Relative Humidity*CO2, Relative Humidity*Sound, Relative Humidity*Light, Relative Humidity*VOC, Relative Humidity*Kind of Workspace, Relative Humidity*Do you sit near (wall type):, Outside temperature*Outside Relative Humidity, Outside temperature*CO2, Outside temperature*Sound, Outside temperature*Light, Outside temperature*VOC, Outside temperature*Kind of Workspace, Outside temperature*Do you sit near (wall type):, Outside Relative Humidity*CO2, Outside Relative Humidity*Sound, Outside Relative Humidity*Light, Outside Relative Humidity*VOC, Outside Relative Humidity*Kind of Workspace, Outside Relative Humidity*Do you sit near (wall type):, CO2*Sound, CO2*Light, CO2*VOC, CO2*Kind of Workspace, CO2*Do you sit near (wall type):, Sound*Light, Sound*VOC, Sound*Kind of Workspace, Sound*Do you sit near (wall type):, Light*VOC, Light*Kind of Workspace, Light*Do you sit near (wall type):, VOC*Kind of Workspace, VOC*Do you sit near (wall type):, Kind of Workspace*Do you sit near (wall type):

	-----Step 1-----		-----Step 2-----	
	Coef	P	Coef	P
Constant	3.224		3.225	
Temperature	0.047	0.941	0.054	0.928
Relative Humidity	-0.870	0.111	-0.865	0.093
Outside temperature	1.298	0.160	1.286	0.152
Outside Relative Humidity	1.066	0.149	1.061	0.144
CO2	0.186	0.665	0.189	0.639
Sound	-0.443	0.323	-0.455	0.264
Light	0.195	0.775	0.188	0.780

VOC	-0.376	0.623	-0.380	0.609
Kind of Workspace	-1.238	0.446	-1.236	0.441
Do you sit near (wall type):	0.161	0.826	0.160	0.821
Temperature*Temperature	-3.429	0.000	-3.438	0.000
Relative Humidity*Relative Humidity	0.461	0.068	0.463	0.064
Outside temperature*Outside temperature	-0.827	0.221	-0.813	0.218
Outside Relative Humidity*Outside Relative Humidity	0.412	0.282	0.418	0.267
CO2*CO2	0.174	0.528	0.176	0.511
Sound*Sound	0.106	0.748	0.109	0.734
Light*Light	0.147	0.592	0.150	0.566
VOC*VOC	-0.594	0.091	-0.595	0.086
Temperature*Relative Humidity	-0.157	0.655	-0.151	0.660
Temperature*Outside temperature	0.011	0.989	0.010	0.990
Temperature*Outside Relative Humidity	-0.070	0.889	-0.068	0.892
Temperature*CO2	-0.754	0.049	-0.755	0.046
Temperature*Sound	-0.174	0.751	-0.152	0.756
Temperature*Light	-0.070	0.872	-0.060	0.887
Temperature*VOC	-0.102	0.769	-0.104	0.764
Temperature*Kind of Workspace	1.12	0.360	1.12	0.331
Temperature*Do you sit near (wall type):	-0.299	0.932	-0.306	0.929
Relative Humidity*Outside temperature	0.855	0.199	0.861	0.187
Relative Humidity*Outside Relative Humidity	0.082	0.845	0.085	0.837
Relative Humidity*CO2	0.320	0.382	0.329	0.348
Relative Humidity*Sound	-0.246	0.463	-0.254	0.434
Relative Humidity*Light	0.211	0.487	0.211	0.479
Relative Humidity*VOC	0.378	0.289	0.371	0.287
Relative Humidity*Kind of Workspace	0.624	0.826	0.628	0.809
Relative Humidity*Do you sit near (wall type):	-0.684	0.434	-0.679	0.406

Outside temperature*Outside Relative Humidity	-0.011	0.991	0.006	0.995
Outside temperature*CO2	-0.918	0.182	-0.922	0.173
Outside temperature*Sound	1.305	0.104	1.311	0.098
Outside temperature*Light	0.010	0.987	0.009	0.988
Outside temperature*VOC	-0.374	0.592	-0.364	0.594
Outside temperature*Kind of Workspace	3.37	0.558	3.37	0.543
Outside temperature*Do you sit near (wall type):	1.076	0.556	-1.08	0.541
Outside Relative Humidity*CO2	-1.022	0.056	-1.021	0.055
Outside Relative Humidity*Sound	1.228	0.031	1.234	0.028
Outside Relative Humidity*Light	-0.290	0.463	-0.290	0.454
Outside Relative Humidity*VOC	-0.262	0.596	-0.254	0.600
Outside Relative Humidity*Kind of Workspace	2.89	0.344	2.90	0.324
Outside Relative Humidity*Do you sit near (wall type):	0.405	0.782	0.401	0.778
CO2*Sound	-0.052	0.896	-0.061	0.875
CO2*Light	-0.236	0.577	-0.243	0.557
CO2*VOC	-0.412	0.280	-0.413	0.274
CO2*Kind of Workspace	-0.746	0.069	-0.745	0.061
CO2*Do you sit near (wall type):	-0.360	0.846	-0.371	0.798
Sound*Light	-0.305	0.425	-0.316	0.378
Sound*VOC	0.176	0.644	0.187	0.607
Sound*Kind of Workspace	-0.637	0.114	-0.638	0.077
Sound*Do you sit near (wall type):	-0.024	1.000		
Light*VOC	0.701	0.089	0.703	0.084
Light*Kind of Workspace	2.61	0.194	2.59	0.186
Light*Do you sit near (wall type):	1.420	0.528	1.430	0.504
VOC*Kind of Workspace	-0.47	0.931	-0.47	0.928
VOC*Do you sit near (wall type):	-0.92	0.021	-0.92	0.014

S		0.658554		0.654763
R-sq		77.00%		77.00%
R-sq(adj)		67.42%		67.79%
R-sq(pred)		46.55%		48.59%
	-----Step 3-----		-----Step 4-----	
	Coef	P	Coef	P
Constant	3.225		3.225	
Temperature	0.054	0.928	0.057	0.920
Relative Humidity	-0.865	0.088	-0.864	0.087
Outside temperature	1.288	0.133	1.287	0.130
Outside Relative Humidity	1.062	0.119	1.062	0.117
CO2	0.189	0.637	0.189	0.636
Sound	-0.455	0.263	-0.456	0.252
Light	0.187	0.780	0.188	0.779
VOC	-0.379	0.602	-0.378	0.601
Kind of Workspace	-1.236	0.439	-1.236	0.433
Do you sit near (wall type):	0.160	0.814	0.160	0.811
Temperature*Temperature	-3.438	0.000	-3.438	0.000
Relative Humidity*Relative Humidity	0.463	0.063	0.463	0.062
Outside temperature*Outside temperature	-0.816	0.016	-0.815	0.014
Outside Relative Humidity*Outside Relative Humidity	0.416	0.100	0.415	0.091
CO2*CO2	0.176	0.510	0.176	0.509
Sound*Sound	0.109	0.733	0.109	0.731
Light*Light	0.150	0.565	0.150	0.564
VOC*VOC	-0.595	0.086	-0.595	0.085
Temperature*Relative Humidity	-0.151	0.660	-0.151	0.659

Temperature*Outside temperature	0.011	0.989		
Temperature*Outside Relative Humidity	-0.068	0.891	-0.073	0.834
Temperature*CO2	-0.755	0.045	-0.754	0.041
Temperature*Sound	-0.152	0.756	-0.152	0.755
Temperature*Light	-0.059	0.886	-0.059	0.886
Temperature*VOC	-0.104	0.763	-0.103	0.763
Temperature*Kind of Workspace	1.12	0.329	1.12	0.317
Temperature*Do you sit near (wall type):	-0.306	0.929	-0.306	0.927
Relative Humidity*Outside temperature	0.862	0.151	0.861	0.147
Relative Humidity*Outside Relative Humidity	0.086	0.826	0.086	0.826
Relative Humidity*CO2	0.329	0.344	0.330	0.335
Relative Humidity*Sound	-0.254	0.433	-0.254	0.430
Relative Humidity*Light	0.210	0.476	0.210	0.473
Relative Humidity*VOC	0.371	0.286	0.371	0.284
Relative Humidity*Kind of Workspace	0.628	0.808	0.628	0.806
Relative Humidity*Do you sit near (wall type):	-0.679	0.405	-0.679	0.402
Outside temperature*Outside Relative Humidity				
Outside temperature*CO2	-0.922	0.172	-0.921	0.170
Outside temperature*Sound	1.311	0.095	1.315	0.069
Outside temperature*Light	0.009	0.988	0.010	0.987
Outside temperature*VOC	-0.366	0.575	-0.366	0.574
Outside temperature*Kind of Workspace	3.37	0.539	3.37	0.529
Outside temperature*Do you sit near (wall type):	-1.08	0.530	-1.08	0.522
Outside Relative Humidity*CO2	-1.021	0.054	-1.021	0.053
Outside Relative Humidity*Sound	1.234	0.027	1.236	0.020

Outside Relative Humidity*Light	-0.290	0.453	-0.290	0.451
Outside Relative Humidity*VOC	-0.255	0.592	-0.255	0.591
Outside Relative Humidity*Kind of Workspace	2.90	0.315	2.90	0.312
Outside Relative Humidity*Do you sit near (wall type):	0.400	0.777	0.400	0.776
CO2*Sound	-0.061	0.875	-0.062	0.872
CO2*Light	-0.243	0.556	-0.242	0.550
CO2*VOC	-0.413	0.270	-0.413	0.267
CO2*Kind of Workspace	-0.745	0.059	-0.746	0.054
CO2*Do you sit near (wall type):	-0.371	0.797	-0.372	0.792
Sound*Light	-0.316	0.376	-0.316	0.375
Sound*VOC	0.186	0.602	0.186	0.598
Sound*Kind of Workspace	-0.638	0.076	-0.638	0.075
Sound*Do you sit near (wall type):				
Light*VOC	0.703	0.082	0.704	0.077
Light*Kind of Workspace	2.59	0.183	2.59	0.179
Light*Do you sit near (wall type):	1.430	0.497	1.430	0.495
VOC*Kind of Workspace	-0.47	0.924	-0.47	0.923
VOC*Do you sit near (wall type):	-0.92	0.013	-0.92	0.013
S		0.653507		0.652259
R-sq		77.00%		77.00%
R-sq(adj)		67.92%		68.04%
R-sq(pred)		49.04%		49.52%
	-----Step 5-----		------Step 6-----	
	Coef	P	Coef	P

Constant	3.225		3.214	
Temperature	0.058	0.918	0.143	0.780
Relative Humidity	-0.864	0.086	-0.819	0.094
Outside temperature	1.286	0.129	1.265	0.132
Outside Relative Humidity	1.062	0.117	1.055	0.115
CO2	0.188	0.634	0.126	0.736
Sound	-0.456	0.251	-0.469	0.234
Light	0.190	0.772	0.196	0.762
VOC	-0.379	0.600	-0.422	0.554
Kind of Workspace	-1.237	0.430	-1.228	0.407
Do you sit near (wall type):	0.160	0.809	0.160	0.822
Temperature*Temperature	-3.438	0.000	-3.391	0.000
Relative Humidity*Relative Humidity	0.463	0.062	0.459	0.060
Outside temperature*Outside temperature	-0.815	0.013	-0.812	0.013
Outside Relative Humidity*Outside Relative Humidity	0.416	0.089	0.426	0.077
CO2*CO2	0.175	0.505	0.172	0.507
Sound*Sound	0.109	0.731	0.134	0.651
Light*Light	0.149	0.563	0.131	0.607
VOC*VOC	-0.594	0.084	-0.591	0.078
Temperature*Relative Humidity	-0.151	0.657	-0.137	0.683
Temperature*Outside temperature				
Temperature*Outside Relative Humidity	-0.072	0.834	-0.065	0.849
Temperature*CO2	-0.753	0.039	-0.720	0.040
Temperature*Sound	-0.152	0.754	-0.208	0.658

Temperature*Light	-0.059	0.886	-0.030	0.936
Temperature*VOC	-0.103	0.762	-0.097	0.773
Temperature*Kind of Workspace	1.12	0.315	1.15	0.335
Temperature*Do you sit near (wall type):	-0.305	0.926		
Relative Humidity*Outside temperature	0.861	0.146	0.852	0.142
Relative Humidity*Outside Relative Humidity	0.086	0.826	0.089	0.819
Relative Humidity*CO2	0.329	0.331	0.351	0.296
Relative Humidity*Sound	-0.253	0.423	-0.268	0.387
Relative Humidity*Light	0.210	0.472	0.222	0.442
Relative Humidity*VOC	0.371	0.283	0.389	0.256
Relative Humidity*Kind of Workspace	0.627	0.799	0.604	0.808
Relative Humidity*Do you sit near (wall type):	-0.678	0.396	-0.552	0.412
Outside temperature*Outside Relative Humidity				
Outside temperature*CO2	-0.919	0.163	-0.945	0.144
Outside temperature*Sound	1.313	0.066	1.309	0.064
Outside temperature*Light				
Outside temperature*VOC	-0.363	0.565	-0.387	0.534
Outside temperature*Kind of Workspace	3.37	0.524	3.35	0.507
Outside temperature*Do you sit near (wall type):	-1.08	0.505	-1.18	0.465
Outside Relative Humidity*CO2	-1.020	0.052	-1.006	0.048
Outside Relative Humidity*Sound	1.235	0.019	1.232	0.017
Outside Relative Humidity*Light	-0.294	0.302	-0.281	0.316
Outside Relative Humidity*VOC	-0.254	0.590	-0.255	0.585
Outside Relative Humidity*Kind of Workspace	2.90	0.310	2.84	0.318
Outside Relative Humidity*Do you sit near (wall type):	0.398	0.757	0.440	0.731

CO2*Sound	-0.062	0.872	-0.076	0.841
CO2*Light	-0.242	0.549	-0.218	0.578
CO2*VOC	-0.413	0.264	-0.399	0.275
CO2*Kind of Workspace	-0.746	0.053	-0.760	0.041
CO2*Do you sit near (wall type):	-0.373	0.790	-0.556	0.640
Sound*Light	-0.317	0.372	-0.328	0.351
Sound*VOC	0.187	0.587	0.207	0.542
Sound*Kind of Workspace	-0.638	0.074	-0.647	0.049
Sound*Do you sit near (wall type):				
Light*VOC	0.705	0.074	0.732	0.061
Light*Kind of Workspace	2.59	0.174	2.58	0.184
Light*Do you sit near (wall type):	1.430	0.492	1.469	0.451
VOC*Kind of Workspace	-0.47	0.921	-0.5201	0.917
VOC*Do you sit near (wall type):	-0.92	0.012	-1.03	0.009
S		0.651018		0.647910
R-sq		77.00%		76.96%
R-sq(adj)		68.16%		68.46%
R-sq(pred)		50.33%		51.03%

	------Step 7-----		-----Step 8-----	
	Coef	P	Coef	P
Constant	3.214		3.278	
Temperature	0.139	0.785	0.102	0.833
Relative Humidity	-0.820	0.093	-0.723	0.089
Outside temperature	1.268	0.130	1.049	0.125
Outside Relative Humidity	1.057	0.114	0.841	0.087

CO2	0.131	0.721	0.196	0.579
Sound	-0.471	0.232	-0.510	0.177
Light	0.193	0.766	0.144	0.801
VOC	-0.423	0.553	-0.122	0.793
Kind of Workspace	-1.231	0.398	-1.104	0.305
Do you sit near (wall type):	0.161	0.810	0.173	0.690
Temperature*Temperature	-3.390	0.000	-3.337	0.000
Relative Humidity*Relative Humidity	0.459	0.059	0.457	0.057
Outside temperature*Outside temperature	-0.811	0.012	-0.844	0.008
Outside Relative Humidity*Outside Relative Humidity	0.426	0.076	0.453	0.055
CO2*CO2	0.174	0.500	0.182	0.472
Sound*Sound	0.133	0.653	0.161	0.578
Light*Light	0.127	0.610	0.132	0.592
VOC*VOC	-0.588	0.078	-0.564	0.086
Temperature*Relative Humidity	-0.135	0.687	-0.129	0.695
Temperature*Outside temperature				
Temperature*Outside Relative Humidity	-0.065	0.849	-0.072	0.830
Temperature*CO2	-0.722	0.038	-0.739	0.033
Temperature*Sound	-0.204	0.662	-0.259	0.574
Temperature*Light				
Temperature*VOC	-0.095	0.777	-0.092	0.779
Temperature*Kind of Workspace	1.14	0.317	0.982	0.264
Temperature*Do you sit near (wall type):				
Relative Humidity*Outside temperature	0.850	0.142	0.835	0.144

Relative Humidity*Outside Relative Humidity	0.091	0.813	0.090	0.812
Relative Humidity*CO2	0.351	0.293	0.343	0.300
Relative Humidity*Sound	-0.270	0.380	-0.271	0.367
Relative Humidity*Light	0.220	0.443	0.215	0.448
Relative Humidity*VOC	0.387	0.256	0.389	0.245
Relative Humidity*Kind of Workspace	0.607	0.805	-0.480	0.866
Relative Humidity*Do you sit near (wall type):	-0.551	0.402	-0.589	0.384
Outside temperature*Outside Relative Humidity				
Outside temperature*CO2	-0.955	0.132	-0.998	0.110
Outside temperature*Sound	1.313	0.062	1.300	0.058
Outside temperature*Light				
Outside temperature*VOC	-0.393	0.524	-0.514	0.391
Outside temperature*Kind of Workspace	3.35	0.498	2.96	0.284
Outside temperature*Do you sit near (wall type):	-1.18	0.457	-1.18	0.485
Outside Relative Humidity*CO2	-1.009	0.046	-0.997	0.046
Outside Relative Humidity*Sound	1.233	0.017	1.191	0.020
Outside Relative Humidity*Light	-0.276	0.311	-0.258	0.337
Outside Relative Humidity*VOC	-0.257	0.581	-0.309	0.500
Outside Relative Humidity*Kind of Workspace	2.84	0.316	2.39	0.083
Outside Relative Humidity*Do you sit near (wall type):	0.444	0.724	0.420	0.743
CO2*Sound	-0.076	0.841	-0.055	0.883
CO2*Light	-0.225	0.557	-0.250	0.508
CO2*VOC	-0.398	0.276	-0.415	0.250
CO2*Kind of Workspace	-0.759	0.039	-	0.041

			0.812	
CO2*Do you sit near (wall type):	-0.554	0.640	-0.481	0.661
Sound*Light	-0.334	0.332	-0.320	0.341
Sound*VOC	0.205	0.544	0.251	0.442
Sound*Kind of Workspace	-0.649	0.046	-0.684	0.028
Sound*Do you sit near (wall type):				
Light*VOC	0.726	0.058	0.612	0.056
Light*Kind of Workspace	2.58	0.154	2.20	0.083
Light*Do you sit near (wall type):	1.469	0.450	1.455	0.421
VOC*Kind of Workspace	-0.5281	0.917		
VOC*Do you sit near (wall type):	-1.03	0.008	-0.85	0.005
S		0.646703		0.643056
R-sq		76.95%		76.87%
R-sq(adj)		68.58%		68.94%
R-sq(pred)		51.33%		54.27%
	-----Step 9-----		-----Step 10----	
	Coef	P	Coef	P
Constant	3.269		3.316	
Temperature	0.103	0.833	0.140	0.725
Relative Humidity	-0.727	0.087	-0.628	0.071
Outside temperature	1.045	0.125	0.924	0.124
Outside Relative Humidity	0.829	0.086	0.775	0.050
CO2	0.184	0.591	0.223	0.502
Sound	-0.488	0.159	-0.543	0.110
Light	0.143	0.802	0.144	0.798
VOC	-0.136	0.765	-0.094	0.836

Kind of Workspace	-1.116	0.271	-1.045	0.292
Do you sit near (wall type):	0.176	0.671	0.165	0.687
Temperature*Temperature	-3.331	0.000	-3.347	0.000
Relative Humidity*Relative Humidity	0.459	0.055	0.427	0.070
Outside temperature*Outside temperature	-0.844	0.008	-0.807	0.010
Outside Relative Humidity*Outside Relative Humidity	0.454	0.054	0.459	0.050
CO2*CO2	0.178	0.479	0.174	0.486
Sound*Sound	0.158	0.584	0.152	0.592
Light*Light	0.133	0.589	0.141	0.564
VOC*VOC	-0.552	0.083	-0.529	0.093
Temperature*Relative Humidity	-0.132	0.687	-0.085	0.788
Temperature*Outside temperature				
Temperature*Outside Relative Humidity	-0.075	0.824	-0.077	0.815
Temperature*CO2	-0.760	0.016	-0.744	0.016
Temperature*Sound	-0.270	0.550	-0.254	0.567
Temperature*Light				
Temperature*VOC	-0.094	0.774	-0.075	0.817
Temperature*Kind of Workspace	0.978	0.258	1.047	0.176
Temperature*Do you sit near (wall type):				
Relative Humidity*Outside temperature	0.843	0.137	0.748	0.173
Relative Humidity*Outside Relative Humidity	0.089	0.814	0.029	0.938
Relative Humidity*CO2	0.337	0.304	0.257	0.412
Relative Humidity*Sound	-0.259	0.369	-0.227	0.425
Relative Humidity*Light	0.216	0.445	0.166	0.518
Relative Humidity*VOC	0.395	0.234	0.439	0.167

Relative Humidity*Kind of Workspace	-0.479	0.868		
Relative Humidity*Do you sit near (wall type):	-0.587	0.376	-0.465	0.425
Outside temperature*Outside Relative Humidity				
Outside temperature*CO2	-1.003	0.107	-0.912	0.126
Outside temperature*Sound	1.302	0.057	1.227	0.069
Outside temperature*Light				
Outside temperature*VOC	-0.498	0.397	-0.527	0.364
Outside temperature*Kind of Workspace	3.00	0.260	2.69	0.280
Outside temperature*Do you sit near (wall type):	-1.17	0.485	-1.16	0.520
Outside Relative Humidity*CO2	-1.017	0.034	-0.950	0.039
Outside Relative Humidity*Sound	1.206	0.016	1.142	0.019
Outside Relative Humidity*Light	-0.259	0.335	-0.269	0.306
Outside Relative Humidity*VOC	-0.303	0.505	-0.304	0.495
Outside Relative Humidity*Kind of Workspace	2.41	0.079	2.323	0.086
Outside Relative Humidity*Do you sit near (wall type):	0.418	0.743	0.375	0.791
CO2*Sound				
CO2*Light	-0.244	0.515	-0.307	0.402
CO2*VOC	-0.411	0.252	-0.361	0.299
CO2*Kind of Workspace	0.796	0.034	0.616	0.036
CO2*Do you sit near (wall type):	0.480	0.663	0.335	0.730
Sound*Light	0.324	0.332	0.308	0.348
Sound*VOC	0.260	0.418	0.259	0.412
Sound*Kind of Workspace	-0.680	0.027	-0.626	0.018
Sound*Do you sit near (wall type):				
Light*VOC	0.606	0.056	0.591	0.059

Light*Kind of Workspace	2.19	0.082	2.19	0.064
Light*Do you sit near (wall type):	1.448	0.423	1.462	0.392
VOC*Kind of Workspace				
VOC*Do you sit near (wall type):	-0.85	0.005	-0.77	0.005
S		0.641899		0.638702
R-sq		76.87%		76.76%
R-sq(adj)		69.05%		69.35%
R-sq(pred)		54.82%		59.29%
	-----Step 11----		-----Step 12----	
	Coef	P	Coef	P
Constant	3.315		3.320	
Temperature	0.139	0.726	0.121	0.756
Relative Humidity	-0.625	0.070	-0.622	0.070
Outside temperature	0.924	0.123	0.917	0.125
Outside Relative Humidity	0.776	0.050	0.777	0.049
CO2	0.221	0.504	0.229	0.485
Sound	-0.541	0.110	-0.537	0.111
Light	0.143	0.799	0.135	0.809
VOC	-0.089	0.842	-0.087	0.846
Kind of Workspace	-1.043	0.288	-1.032	0.292
Do you sit near (wall type):	0.164	0.687	0.164	0.691
Temperature*Temperature	-3.348	0.000	-3.348	0.000
Relative Humidity*Relative Humidity	0.431	0.059	0.436	0.054
Outside temperature*Outside temperature	-0.804	0.010	-0.797	0.010
Outside Relative Humidity*Outside Relative Humidity	0.461	0.048	0.461	0.048
CO2*CO2	0.174	0.483	0.170	0.492

Sound*Sound	0.150	0.594	0.140	0.614
Light*Light	0.138	0.567	0.142	0.554
VOC*VOC	-0.531	0.090	-0.538	0.083
Temperature*Relative Humidity	-0.083	0.793	-0.074	0.812
Temperature*Outside temperature				
Temperature*Outside Relative Humidity	-0.077	0.814	-0.063	0.845
Temperature*CO2	-0.743	0.016	-0.733	0.016
Temperature*Sound	-0.254	0.567	-0.234	0.590
Temperature*Light				
Temperature*VOC	-0.074	0.819		
Temperature*Kind of Workspace	1.045	0.175	1.055	0.177
Temperature*Do you sit near (wall type):				
Relative Humidity*Outside temperature	0.717	0.062	0.708	0.064
Relative Humidity*Outside Relative Humidity				
Relative Humidity*CO2	0.255	0.413	0.254	0.415
Relative Humidity*Sound	-0.230	0.412	-0.232	0.408
Relative Humidity*Light	0.168	0.512	0.163	0.522
Relative Humidity*VOC	0.441	0.164	0.436	0.167
Relative Humidity*Kind of Workspace				
Relative Humidity*Do you sit near (wall type):	-0.464	0.425	-0.462	0.421
Outside temperature*Outside Relative Humidity				
Outside temperature*CO2	-0.921	0.115	-0.930	0.110
Outside temperature*Sound	1.217	0.065	1.209	0.066
Outside temperature*Light				
Outside temperature*VOC	-0.533	0.354	-0.534	0.352
Outside temperature*Kind of Workspace	2.69	0.278	2.70	0.276

Outside temperature*Do you sit near (wall type):	-1.16	0.516	-1.16	0.516
Outside Relative Humidity*CO2	-0.959	0.032	-0.972	0.028
Outside Relative Humidity*Sound	1.137	0.019	1.135	0.019
Outside Relative Humidity*Light	-0.267	0.306	-0.266	0.307
Outside Relative Humidity*VOC	-0.308	0.485	-0.314	0.476
Outside Relative Humidity*Kind of Workspace	2.318	0.085	2.328	0.082
Outside Relative Humidity*Do you sit near (wall type):	0.376	0.782	0.375	0.781
CO2*Sound				
CO2*Light	-0.304	0.404	-0.306	0.399
CO2*VOC	-0.359	0.299	-0.372	0.274
CO2*Kind of Workspace	-0.620	0.034	-0.609	0.034
CO2*Do you sit near (wall type):	-0.335	0.728	-0.338	0.727
Sound*Light	-0.307	0.348	-0.310	0.342
Sound*VOC	0.257	0.413	0.221	0.416
Sound*Kind of Workspace	-0.625	0.017	0.622	0.017
Sound*Do you sit near (wall type):				
Light*VOC	0.595	0.055	0.590	0.056
Light*Kind of Workspace	2.19	0.062	2.12	0.062
Light*Do you sit near (wall type):	1.463	0.391	1.467	0.391
VOC*Kind of Workspace				
VOC*Do you sit near (wall type):	-0.77	0.005	-0.77	0.005
S		0.637555		0.636467
R-sq		76.76%		76.76%
R-sq(adj)		69.46%		69.57%

R-sq(pred)		59.54%		59.97%
	-----Step 13----		-----Step 14----	
	Coef	P	Coef	P
Constant	3.324		3.317	
Temperature	0.142	0.704	0.164	0.649
Relative Humidity	-0.616	0.071	-0.612	0.073
Outside temperature	0.907	0.127	0.900	0.129
Outside Relative Humidity	0.775	0.049	0.773	0.049
CO2	0.226	0.490	0.216	0.505
Sound	-0.538	0.110	-0.545	0.104
Light	0.137	0.806	0.142	0.799
VOC	-0.088	0.844	-0.091	0.838
Kind of Workspace	-1.022	0.294	-1.043	0.274
Do you sit near (wall type):	0.170	0.646	0.175	0.639
Temperature*Temperature	-3.343	0.000	-3.331	0.000
Relative Humidity*Relative Humidity	0.434	0.054	0.440	0.050
Outside temperature*Outside temperature	-0.798	0.010	-0.794	0.010
Outside Relative Humidity*Outside Relative Humidity	0.462	0.047	0.461	0.047
CO2*CO2	0.172	0.487	0.168	0.494
Sound*Sound	0.135	0.625	0.126	0.645
Light*Light	0.147	0.536	0.151	0.524
VOC*VOC	-0.538	0.082	-0.543	0.078
Temperature*Relative Humidity	-0.078	0.804		
Temperature*Outside temperature				
Temperature*Outside Relative Humidity				
Temperature*CO2	-0.720	0.015	-0.705	0.015

Temperature*Sound	-0.237	0.584	-0.251	0.559
Temperature*Light				
Temperature*VOC				
Temperature*Kind of Workspace	1.058	0.177	1.066	0.176
Temperature*Do you sit near (wall type):				
Relative Humidity*Outside temperature	0.701	0.065	0.693	0.066
Relative Humidity*Outside Relative Humidity				
Relative Humidity*CO2	0.259	0.404	0.247	0.419
Relative Humidity*Sound	-0.223	0.420	-0.257	0.285
Relative Humidity*Light	0.168	0.505	0.172	0.494
Relative Humidity*VOC	0.438	0.164	0.439	0.162
Relative Humidity*Kind of Workspace				
Relative Humidity*Do you sit near (wall type):	-0.459	0.426	-0.444	0.420
Outside temperature*Outside Relative Humidity				
Outside temperature*CO2	-0.932	0.109	-0.958	0.093
Outside temperature*Sound	1.189	0.067	1.204	0.063
Outside temperature*Light				
Outside temperature*VOC	-0.538	0.348	-0.534	0.350
Outside temperature*Kind of Workspace	2.70	0.271	2.75	0.244
Outside temperature*Do you sit near (wall type):	-1.17	0.504	-1.19	0.475
Outside Relative Humidity*CO2	-0.981	0.025	-0.988	0.024
Outside Relative Humidity*Sound	1.105	0.015	1.122	0.013
Outside Relative Humidity*Light	-0.271	0.296	-0.266	0.303
Outside Relative Humidity*VOC	-0.315	0.474	-0.301	0.489
Outside Relative Humidity*Kind of Workspace	2.343	0.080	2.362	0.074
Outside Relative Humidity*Do you sit near (wall type):	0.376	0.787	0.387	0.772

CO2*Sound				
CO2*Light	-0.309	0.392	-0.306	0.396
CO2*VOC	-0.373	0.272	-0.367	0.277
CO2*Kind of Workspace	-0.597	0.034	-0.591	0.034
CO2*Do you sit near (wall type):	-0.339	0.734	-0.350	0.726
Sound*Light	-0.304	0.348	-0.316	0.325
Sound*VOC	0.221	0.416	0.220	0.417
Sound*Kind of Workspace	-0.616	0.017	0.617	0.017
Sound*Do you sit near (wall type):				
Light*VOC	0.586	0.057	0.580	0.058
Light*Kind of Workspace	2.08	0.061	2.06	0.062
Light*Do you sit near (wall type):	1.476	0.385	1.485	0.379
VOC*Kind of Workspace				
VOC*Do you sit near (wall type):	-0.79	0.005	-0.81	0.004
S		0.635369		0.634304
R-sq		76.76%		76.75%
R-sq(adj)		69.67%		69.78%
R-sq(pred)		60.38%		60.61%
	-----Step 15----		-----Step 16----	
	Coef	P	Coef	P
Constant	3.294		3.305	
Temperature	0.222	0.532	0.230	0.515
Relative Humidity	-0.601	0.048	-0.591	0.051
Outside temperature	0.881	0.099	0.882	0.098
Outside Relative Humidity	0.755	0.034	0.755	0.034
CO2	0.230	0.456	0.214	0.484

Sound	-0.494	0.131	-0.482	0.139
Light	0.074	0.884	0.073	0.885
VOC	-0.076	0.848	-0.097	0.805
Kind of Workspace	-0.977	0.296	-0.973	0.291
Do you sit near (wall type):	0.163	0.661	0.171	0.632
Temperature*Temperature	-3.367	0.000	-3.394	0.000
Relative Humidity*Relative Humidity	0.461	0.039	0.463	0.038
Outside temperature*Outside temperature	-0.791	0.009	-0.795	0.008
Outside Relative Humidity*Outside Relative Humidity	0.464	0.041	0.466	0.040
CO2*CO2	0.162	0.507	0.174	0.473
Sound*Sound	0.118	0.661		
Light*Light	0.192	0.410	0.194	0.403
VOC*VOC	-0.523	0.087	-0.488	0.098
Temperature*Relative Humidity				
Temperature*Outside temperature				
Temperature*Outside Relative Humidity				
Temperature*CO2	-0.691	0.016	-0.704	0.013
Temperature*Sound	-0.207	0.626	-0.099	0.774
Temperature*Light				
Temperature*VOC				
Temperature*Kind of Workspace	1.226	0.175	1.260	0.179
Temperature*Do you sit near (wall type):				
Relative Humidity*Outside temperature	0.698	0.062	0.680	0.067
Relative Humidity*Outside Relative Humidity				
Relative Humidity*CO2	0.235	0.440	0.246	0.416
Relative Humidity*Sound	-0.278	0.242	-0.279	0.240

Relative Humidity*Light	0.162	0.519	0.162	0.517
Relative Humidity*VOC	0.420	0.178	0.427	0.170
Relative Humidity*Kind of Workspace				
Relative Humidity*Do you sit near (wall type):	-0.480	0.360	-0.483	0.365
Outside temperature*Outside Relative Humidity				
Outside temperature*CO2	-0.966	0.085	-0.936	0.092
Outside temperature*Sound	1.220	0.057	1.135	0.063
Outside temperature*Light				
Outside temperature*VOC	-0.534	0.347	-0.536	0.344
Outside temperature*Kind of Workspace	2.54	0.291	2.48	0.293
Outside temperature*Do you sit near (wall type):	-1.003	0.204	-1.024	0.190
Outside Relative Humidity*CO2	-0.992	0.020	-0.965	0.022
Outside Relative Humidity*Sound	1.171	0.008	1.130	0.009
Outside Relative Humidity*Light	-0.328	0.190	-0.332	0.184
Outside Relative Humidity*VOC	-0.278	0.518	-0.261	0.542
Outside Relative Humidity*Kind of Workspace	2.252	0.073	2.219	0.076
Outside Relative Humidity*Do you sit near (wall type):				
CO2*Sound				
CO2*Light	-0.343	0.337	-0.346	0.333
CO2*VOC	-0.336	0.316	-0.320	0.336
CO2*Kind of Workspace	0.6213	0.031	-0.613	0.031
CO2*Do you sit near (wall type):	-0.339	0.658	-0.351	0.659
Sound*Light	-0.310	0.330	-0.303	0.339

Sound*VOC	0.215	0.425	0.188	0.474
Sound*Kind of Workspace	-0.635	0.022	- 0.603	0.018
Sound*Do you sit near (wall type):				
Light*VOC	0.575	0.059	0.572	0.060
Light*Kind of Workspace	2.01	0.061	2.00	0.063
Light*Do you sit near (wall type):	1.449	0.138	1.442	0.141
VOC*Kind of Workspace				
VOC*Do you sit near (wall type):	-0.785	0.004	- 0.785	0.003
S		0.632194		0.631295
R-sq		76.66%		76.64%
R-sq(adj)		69.98%		70.06%
R-sq(pred)		62.40%		62.69%

	-----Step 17----		-----Step 18-----	
	Coef	P	Coef	P
Constant	3.307		3.332	
Temperature	0.219	0.533	0.197	0.571
Relative Humidity	- 0.602	0.045	-0.680	0.013
Outside temperature	0.903	0.087	0.981	0.057
Outside Relative Humidity	0.764	0.031	0.761	0.030
CO2	0.221	0.468	0.266	0.335
Sound	- 0.484	0.136	-0.495	0.123
Light	0.063	0.901	0.004	0.993
VOC	- 0.079	0.839	-0.000	1.000
Kind of Workspace	- 0.978	0.296	-1.005	0.206
Do you sit near (wall type):	0.171	0.624	- 0.2614	0.189
Temperature*Temperature	-	0.000	-3.467	0.000

	3.451			
Relative Humidity*Relative Humidity	0.461	0.038	0.444	0.041
Outside temperature*Outside temperature	-0.790	0.008	-0.787	0.008
Outside Relative Humidity*Outside Relative Humidity	0.464	0.040	0.432	0.052
CO2*CO2	0.175	0.471	0.190	0.430
Sound*Sound				
Light*Light	0.191	0.408	0.184	0.423
VOC*VOC	-0.485	0.099	-0.439	0.130
Temperature*Relative Humidity				
Temperature*Outside temperature				
Temperature*Outside Relative Humidity				
Temperature*CO2	-0.709	0.013	-0.640	0.018
Temperature*Sound				
Temperature*Light				
Temperature*VOC				
Temperature*Kind of Workspace	1.243	0.181	1.183	0.220
Temperature*Do you sit near (wall type):				
Relative Humidity*Outside temperature	0.673	0.069	0.659	0.073
Relative Humidity*Outside Relative Humidity				
Relative Humidity*CO2	0.245	0.417	0.206	0.471
Relative Humidity*Sound	-0.272	0.249	-0.274	0.242
Relative Humidity*Light	0.162	0.517	0.164	0.510
Relative Humidity*VOC	0.438	0.156	0.453	0.139
Relative Humidity*Kind of Workspace				
Relative Humidity*Do you sit near (wall type):	-0.489	0.327	-0.636	0.170
Outside temperature*Outside Relative Humidity				
Outside temperature*CO2	-0.922	0.095	-0.902	0.101
Outside temperature*Sound	1.109	0.066	1.110	0.063

Outside temperature*Light				
Outside temperature*VOC	-0.549	0.330	-0.593	0.288
Outside temperature*Kind of Workspace	2.51	0.274	2.56	0.278
Outside temperature*Do you sit near (wall type):	-1.011	0.195	-0.873	0.266
Outside Relative Humidity*CO2	-0.953	0.023	-0.953	0.021
Outside Relative Humidity*Sound	1.098	0.009	1.080	0.009
Outside Relative Humidity*Light	-0.330	0.186	-0.348	0.160
Outside Relative Humidity*VOC	-0.274	0.518	-0.348	0.405
Outside Relative Humidity*Kind of Workspace	2.218	0.077	2.191	0.078
Outside Relative Humidity*Do you sit near (wall type):				
CO2*Sound				
CO2*Light	-0.352	0.323	-0.365	0.276
CO2*VOC	-0.306	0.352	-0.289	0.373
CO2*Kind of Workspace	0.6135	0.032	-0.557	0.043
CO2*Do you sit near (wall type):	-0.332	0.669		
Sound*Light	-0.306	0.333	-0.323	0.303
Sound*VOC	0.185	0.479	0.220	0.395
Sound*Kind of Workspace	-0.594	0.018	-0.619	0.009
Sound*Do you sit near (wall type):				
Light*VOC	0.573	0.059	0.614	0.040
Light*Kind of Workspace	1.96	0.063	1.95	0.058
Light*Do you sit near (wall type):	1.424	0.145	1.292	0.178
VOC*Kind of Workspace				
VOC*Do you sit near (wall type):	-	0.003	0.6064	0.003

	0.751			
S		0.630278		0.628699
R-sq		76.63%		76.51%
R-sq(adj)		70.16%		70.31%
R-sq(pred)		62.96%		63.48%

	-----Step 19-----	
	Coef	P
Constant	3.331	
Temperature	0.203	0.557
Relative Humidity	-0.684	0.012
Outside temperature	0.965	0.060
Outside Relative Humidity	0.752	0.032
CO2	0.265	0.336
Sound	-0.504	0.115
Light	-0.010	0.984
VOC	-0.023	0.949
Kind of Workspace	-1.029	0.200
Do you sit near (wall type):	-0.2629	0.185
Temperature*Temperature	-3.473	0.000
Relative Humidity*Relative Humidity	0.422	0.049
Outside temperature*Outside temperature	-0.797	0.007
Outside Relative Humidity*Outside Relative Humidity	0.456	0.038
CO2*CO2	0.193	0.422
Sound*Sound		
Light*Light	0.172	0.452
VOC*VOC	-0.435	0.133
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.639	0.018
Temperature*Sound		
Temperature*Light		

Temperature*VOC		
Temperature*Kind of Workspace	1.220	0.195
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.702	0.052
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2	0.188	0.509
Relative Humidity*Sound	-0.276	0.239
Relative Humidity*Light		
Relative Humidity*VOC	0.406	0.172
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.584	0.191
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.855	0.116
Outside temperature*Sound	1.124	0.060
Outside temperature*Light		
Outside temperature*VOC	-0.563	0.311
Outside temperature*Kind of Workspace	2.65	0.276
Outside temperature*Do you sit near (wall type):	-0.880	0.268
Outside Relative Humidity*CO2	-0.920	0.025
Outside Relative Humidity*Sound	1.088	0.008
Outside Relative Humidity*Light	-0.337	0.173
Outside Relative Humidity*VOC	-0.320	0.441
Outside Relative Humidity*Kind of Workspace	2.213	0.075
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.417	0.201
CO2*VOC	-0.322	0.314
CO2*Kind of Workspace	-0.574	0.035
CO2*Do you sit near (wall type):		
Sound*Light	-0.334	0.287
Sound*VOC	0.241	0.347
Sound*Kind of Workspace	-0.622	0.008
Sound*Do you sit near (wall type):		

Light*VOC	0.606	0.043
Light*Kind of Workspace	1.93	0.059
Light*Do you sit near (wall type):	1.334	0.163
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.6054	0.004
S		0.628085
R-sq		76.47%
R-sq(adj)		70.37%
R-sq(pred)		63.75%
	-----Step 20-----	
	Coef	P
Constant	3.321	
Temperature	0.222	0.519
Relative Humidity	-0.741	0.004
Outside temperature	0.949	0.064
Outside Relative Humidity	0.754	0.031
CO2	0.228	0.398
Sound	-0.511	0.110
Light	0.026	0.958
VOC	-0.044	0.902
Kind of Workspace	-1.045	0.171
Do you sit near (wall type):	-0.2647	0.188
Temperature*Temperature	-3.472	0.000
Relative Humidity*Relative Humidity	0.399	0.059
Outside temperature*Outside temperature	-0.788	0.008
Outside Relative Humidity*Outside Relative Humidity	0.475	0.029
CO2*CO2	0.163	0.489
Sound*Sound		
Light*Light	0.195	0.389
VOC*VOC	-0.476	0.092
Temperature*Relative Humidity		
Temperature*Outside temperature		

Temperature*Outside Relative Humidity		
Temperature*CO2	-0.636	0.018
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.201	0.155
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.736	0.040
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound	-0.225	0.309
Relative Humidity*Light		
Relative Humidity*VOC	0.369	0.206
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.529	0.218
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.804	0.135
Outside temperature*Sound	1.092	0.066
Outside temperature*Light		
Outside temperature*VOC	-0.542	0.327
Outside temperature*Kind of Workspace	2.67	0.280
Outside temperature*Do you sit near (wall type):	-0.878	0.268
Outside Relative Humidity*CO2	-0.884	0.030
Outside Relative Humidity*Sound	1.079	0.008
Outside Relative Humidity*Light	-0.336	0.175
Outside Relative Humidity*VOC	-0.297	0.472
Outside Relative Humidity*Kind of Workspace	2.232	0.059
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.440	0.173
CO2*VOC	-0.354	0.263
CO2*Kind of Workspace	-0.571	0.039
CO2*Do you sit near (wall type):		

Sound*Light	-0.307	0.322
Sound*VOC	0.236	0.357
Sound*Kind of Workspace	0.607	0.007
Sound*Do you sit near (wall type):		
Light*VOC	0.574	0.051
Light*Kind of Workspace	1.92	0.060
Light*Do you sit near (wall type):	1.391	0.130
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.6470	0.003
S		0.627476
R-sq		76.44%
R-sq(adj)		70.42%
R-sq(pred)		64.01%
	-----Step 21-----	
	Coef	P
Constant	3.363	
Temperature	0.223	0.517
Relative Humidity	-0.737	0.004
Outside temperature	0.946	0.065
Outside Relative Humidity	0.752	0.031
CO2	0.196	0.461
Sound	-0.493	0.121
Light	0.051	0.916
VOC	-0.056	0.876
Kind of Workspace	-0.984	0.187
Do you sit near (wall type):	-0.2728	0.179
Temperature*Temperature	-3.476	0.000
Relative Humidity*Relative Humidity	0.395	0.061
Outside temperature*Outside temperature	-0.786	0.008
Outside Relative Humidity*Outside Relative Humidity	0.466	0.032
CO2*CO2		
Sound*Sound		

Light*Light	0.203	0.367
VOC*VOC	-0.442	0.112
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.585	0.024
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.217	0.180
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.732	0.040
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound	-0.227	0.302
Relative Humidity*Light		
Relative Humidity*VOC	0.369	0.206
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.551	0.208
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.802	0.136
Outside temperature*Sound	1.102	0.063
Outside temperature*Light		
Outside temperature*VOC	-0.528	0.339
Outside temperature*Kind of Workspace	2.59	0.300
Outside temperature*Do you sit near (wall type):	-0.849	0.294
Outside Relative Humidity*CO2	-0.885	0.029
Outside Relative Humidity*Sound	1.088	0.008
Outside Relative Humidity*Light	-0.317	0.196
Outside Relative Humidity*VOC	-0.300	0.468
Outside Relative Humidity*Kind of Workspace	2.163	0.067
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		

CO2*Light	-0.379	0.222
CO2*VOC	-0.404	0.189
CO2*Kind of Workspace	-0.536	0.036
CO2*Do you sit near (wall type):		
Sound*Light	-0.304	0.327
Sound*VOC	0.219	0.389
Sound*Kind of Workspace	-0.631	0.007
Sound*Do you sit near (wall type):		
Light*VOC	0.579	0.049
Light*Kind of Workspace	-1.894	0.061
Light*Do you sit near (wall type):	1.372	0.137
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.6181	0.004
S		0.626914
R-sq		76.40%
R-sq(adj)		70.48%
R-sq(pred)		64.08%
	-----Step 22-----	
	Coef	P
Constant	3.380	
Temperature	0.215	0.532
Relative Humidity	-0.711	0.005
Outside temperature	0.838	0.087
Outside Relative Humidity	0.664	0.042
CO2	0.176	0.505
Sound	-0.520	0.100
Light	0.071	0.883
VOC	-0.120	0.730
Kind of Workspace	-0.982	0.204
Do you sit near (wall type):	-0.2707	0.187
Temperature*Temperature	-3.461	0.000
Relative Humidity*Relative Humidity	0.389	0.065

Outside temperature*Outside temperature	-0.767	0.009
Outside Relative Humidity*Outside Relative Humidity	0.463	0.033
CO2*CO2		
Sound*Sound		
Light*Light	0.198	0.380
VOC*VOC	-0.439	0.114
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.606	0.018
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.154	0.200
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.713	0.045
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound	-0.253	0.246
Relative Humidity*Light		
Relative Humidity*VOC	0.322	0.257
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.552	0.218
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.766	0.152
Outside temperature*Sound	1.201	0.038
Outside temperature*Light		
Outside temperature*VOC	-0.228	0.534
Outside temperature*Kind of Workspace	2.62	0.288
Outside temperature*Do you sit near (wall type):	-0.875	0.264
Outside Relative Humidity*CO2	-0.865	0.033
Outside Relative Humidity*Sound	1.155	0.004
Outside Relative Humidity*Light	-0.294	0.227

Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace	2.148	0.069
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.385	0.214
CO2*VOC	-0.389	0.204
CO2*Kind of Workspace	-0.570	0.027
CO2*Do you sit near (wall type):		
Sound*Light	-0.316	0.307
Sound*VOC	0.235	0.355
Sound*Kind of Workspace	-0.623	0.008
Sound*Do you sit near (wall type):		
Light*VOC	0.568	0.053
Light*Kind of Workspace	-1.805	0.065
Light*Do you sit near (wall type):	1.437	0.107
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.6702	0.004
S		0.626408
R-sq		76.35%
R-sq(adj)		70.52%
R-sq(pred)		64.06%
	-----Step 23-----	
	Coef	P
Constant	3.402	
Temperature	0.202	0.557
Relative Humidity	-0.718	0.005
Outside temperature	0.781	0.104
Outside Relative Humidity	0.657	0.044
CO2	0.159	0.543
Sound	-0.514	0.103
Light	0.084	0.863
VOC	-0.213	0.499

Kind of Workspace	-0.987	0.204
Do you sit near (wall type):	-0.2541	0.218
Temperature*Temperature	-3.459	0.000
Relative Humidity*Relative Humidity	0.401	0.056
Outside temperature*Outside temperature	-0.762	0.010
Outside Relative Humidity*Outside Relative Humidity	0.467	0.031
CO2*CO2		
Sound*Sound		
Light*Light	0.211	0.345
VOC*VOC	-0.457	0.098
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.608	0.018
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.151	0.219
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.743	0.035
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound	-0.245	0.259
Relative Humidity*Light		
Relative Humidity*VOC	0.311	0.273
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.543	0.222
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.673	0.189
Outside temperature*Sound	1.190	0.039
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	2.64	0.271

Outside temperature*Do you sit near (wall type):	-0.869	0.248
Outside Relative Humidity*CO2	-0.856	0.034
Outside Relative Humidity*Sound	1.173	0.003
Outside Relative Humidity*Light	-0.297	0.221
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace	2.145	0.074
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.381	0.219
CO2*VOC	-0.428	0.153
CO2*Kind of Workspace	-0.591	0.016
CO2*Do you sit near (wall type):		
Sound*Light	-0.334	0.277
Sound*VOC	0.254	0.314
Sound*Kind of Workspace	-0.609	0.006
Sound*Do you sit near (wall type):		
Light*VOC	0.559	0.056
Light*Kind of Workspace	-1.826	0.072
Light*Do you sit near (wall type):	1.456	0.100
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.6705	0.004
S		0.625753
R-sq		76.32%
R-sq(adj)		70.58%
R-sq(pred)		64.20%
	-----Step 24-----	
	Coef	P
Constant	3.425	
Temperature	0.231	0.500
Relative Humidity	-0.726	0.004
Outside temperature	0.759	0.114
Outside Relative Humidity	0.629	0.053

CO2	0.158	0.546
Sound	-0.546	0.081
Light	0.052	0.915
VOC	-0.224	0.478
Kind of Workspace	-1.054	0.146
Do you sit near (wall type):	-0.2599	0.162
Temperature*Temperature	-3.474	0.000
Relative Humidity*Relative Humidity	0.397	0.058
Outside temperature*Outside temperature	-0.791	0.007
Outside Relative Humidity*Outside Relative Humidity	0.473	0.029
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC	-0.439	0.111
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.616	0.016
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.271	0.212
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.731	0.038
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound	-0.238	0.272
Relative Humidity*Light		
Relative Humidity*VOC	0.332	0.240
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.567	0.200
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.630	0.217

Outside temperature*Sound	1.201	0.037
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	2.69	0.244
Outside temperature*Do you sit near (wall type):	-0.894	0.216
Outside Relative Humidity*CO2	-0.854	0.034
Outside Relative Humidity*Sound	1.183	0.003
Outside Relative Humidity*Light	-0.291	0.230
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace	2.120	0.083
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.384	0.215
CO2*VOC	-0.440	0.142
CO2*Kind of Workspace	-0.629	0.009
CO2*Do you sit near (wall type):		
Sound*Light	-0.306	0.317
Sound*VOC	0.259	0.303
Sound*Kind of Workspace	-0.640	0.003
Sound*Do you sit near (wall type):		
Light*VOC	0.643	0.021
Light*Kind of Workspace	1.99	0.019
Light*Do you sit near (wall type):	1.539	0.074
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.6665	0.004
S		0.625642
R-sq		76.25%
R-sq(adj)		70.60%
R-sq(pred)		64.17%
	-----Step 25-----	
	Coef	P
Constant	3.435	

Temperature	0.164	0.624
Relative Humidity	-0.714	0.005
Outside temperature	0.778	0.105
Outside Relative Humidity	0.597	0.065
CO2	0.161	0.539
Sound	-0.549	0.080
Light	0.138	0.772
VOC	-0.235	0.456
Kind of Workspace	-1.094	0.141
Do you sit near (wall type):	-0.2696	0.144
Temperature*Temperature	-3.482	0.000
Relative Humidity*Relative Humidity	0.373	0.074
Outside temperature*Outside temperature	-0.800	0.006
Outside Relative Humidity*Outside Relative Humidity	0.466	0.031
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC	-0.461	0.093
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.651	0.010
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.141	0.241
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.696	0.047
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound	-0.214	0.321
Relative Humidity*Light		
Relative Humidity*VOC	0.300	0.285

Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.601	0.205
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.584	0.250
Outside temperature*Sound	1.186	0.040
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	2.69	0.243
Outside temperature*Do you sit near (wall type):	-0.868	0.241
Outside Relative Humidity*CO2	-0.869	0.031
Outside Relative Humidity*Sound	1.194	0.003
Outside Relative Humidity*Light	-0.271	0.263
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace	2.099	0.081
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.455	0.131
CO2*VOC	-0.494	0.094
CO2*Kind of Workspace	-0.672	0.008
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.272	0.280
Sound*Kind of Workspace	-0.626	0.003
Sound*Do you sit near (wall type):		
Light*VOC	0.637	0.022
Light*Kind of Workspace	2.13	0.007
Light*Do you sit near (wall type):	1.575	0.064
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.6584	0.005
S		0.625647
R-sq		76.17%
R-sq(adj)		70.59%

R-sq(pred)		64.20%
	-----Step 26-----	
	Coef	P
Constant	3.415	
Temperature	0.202	0.545
Relative Humidity	-0.747	0.003
Outside temperature	0.823	0.084
Outside Relative Humidity	0.607	0.060
CO2	0.149	0.569
Sound	-0.568	0.070
Light	0.093	0.844
VOC	-0.222	0.482
Kind of Workspace	-1.177	0.109
Do you sit near (wall type):	-0.2608	0.159
Temperature*Temperature	-3.483	0.000
Relative Humidity*Relative Humidity	0.387	0.063
Outside temperature*Outside temperature	-0.817	0.005
Outside Relative Humidity*Outside Relative Humidity	0.469	0.030
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC	-0.453	0.099
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.621	0.014
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.210	0.232
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.742	0.033
Relative Humidity*Outside Relative Humidity		

Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC	0.371	0.172
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.643	0.154
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.578	0.255
Outside temperature*Sound	1.199	0.037
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	2.84	0.196
Outside temperature*Do you sit near (wall type):	-0.869	0.224
Outside Relative Humidity*CO2	-0.848	0.035
Outside Relative Humidity*Sound	1.176	0.003
Outside Relative Humidity*Light	-0.266	0.272
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace	2.121	0.084
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.460	0.127
CO2*VOC	-0.463	0.114
CO2*Kind of Workspace	-0.640	0.009
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.286	0.254
Sound*Kind of Workspace	-0.631	0.004
Sound*Do you sit near (wall type):		
Light*VOC	0.665	0.017
Light*Kind of Workspace	2.11	0.007
Light*Do you sit near (wall type):	1.527	0.076
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.6529	0.003

S		0.625635
R-sq		76.09%
R-sq(adj)		70.60%
R-sq(pred)		64.61%
	-----Step 27-----	
	Coef	P
Constant	3.389	
Temperature	0.214	0.520
Relative Humidity	-0.770	0.002
Outside temperature	0.848	0.075
Outside Relative Humidity	0.595	0.065
CO2	0.099	0.701
Sound	-0.579	0.065
Light	0.178	0.704
VOC	-0.214	0.497
Kind of Workspace	-1.221	0.101
Do you sit near (wall type):	-0.2692	0.143
Temperature*Temperature	-3.467	0.000
Relative Humidity*Relative Humidity	0.398	0.055
Outside temperature*Outside temperature	-0.787	0.007
Outside Relative Humidity*Outside Relative Humidity	0.473	0.029
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC	-0.439	0.109
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.611	0.015
Temperature*Sound		
Temperature*Light		
Temperature*VOC		

Temperature*Kind of Workspace	1.209	0.228
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.741	0.033
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC	0.377	0.165
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.744	0.089
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.596	0.240
Outside temperature*Sound	1.227	0.033
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	2.86	0.202
Outside temperature*Do you sit near (wall type):	-0.764	0.316
Outside Relative Humidity*CO2	-0.915	0.022
Outside Relative Humidity*Sound	1.185	0.003
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace	2.053	0.105
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.373	0.200
CO2*VOC	-0.464	0.113
CO2*Kind of Workspace	-0.642	0.011
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.280	0.265
Sound*Kind of Workspace	-0.632	0.004
Sound*Do you sit near (wall type):		
Light*VOC	0.667	0.016

Light*Kind of Workspace	2.16	0.007
Light*Do you sit near (wall type):	1.393	0.112
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.6136	0.004
S		0.625859
R-sq		75.99%
R-sq(adj)		70.57%
R-sq(pred)		64.63%
	-----Step 28-----	
	Coef	P
Constant	3.363	
Temperature	0.230	0.491
Relative Humidity	-0.764	0.002
Outside temperature	1.099	0.015
Outside Relative Humidity	0.678	0.034
CO2	0.116	0.651
Sound	-0.534	0.087
Light	-0.032	0.943
VOC	-0.077	0.800
Kind of Workspace	-1.171	0.084
Do you sit near (wall type):	-0.2782	0.013
Temperature*Temperature	-3.491	0.000
Relative Humidity*Relative Humidity	0.396	0.057
Outside temperature*Outside temperature	-0.767	0.008
Outside Relative Humidity*Outside Relative Humidity	0.514	0.017
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC	-0.412	0.132
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		

Temperature*CO2	-0.643	0.011
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.288	0.179
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.726	0.034
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC	0.346	0.198
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.775	0.068
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.533	0.288
Outside temperature*Sound	1.122	0.049
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	2.75	0.238
Outside temperature*Do you sit near (wall type):		
Outside Relative Humidity*CO2	-0.758	0.052
Outside Relative Humidity*Sound	1.103	0.004
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace	1.895	0.171
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.359	0.216
CO2*VOC	-0.475	0.104
CO2*Kind of Workspace	-0.673	0.006
CO2*Do you sit near (wall type):		
Sound*Light		

Sound*VOC	0.334	0.177
Sound*Kind of Workspace	-0.659	0.006
Sound*Do you sit near (wall type):		
Light*VOC	0.606	0.026
Light*Kind of Workspace	2.11	0.006
Light*Do you sit near (wall type):	0.832	0.352
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	-0.522	0.006
S		0.626437
R-sq		75.70%
R-sq(adj)		70.52%
R-sq(pred)		64.94%
	-----Step 29-----	
	Coef	P
Constant	3.397	
Temperature	0.245	0.457
Relative Humidity	-0.842	0.001
Outside temperature	1.169	0.009
Outside Relative Humidity	0.731	0.022
CO2	0.156	0.537
Sound	-0.485	0.118
Light	-0.312	0.457
VOC	0.169	0.522
Kind of Workspace	-1.141	0.090
Do you sit near (wall type):	-0.3156	0.005
Temperature*Temperature	-3.490	0.000
Relative Humidity*Relative Humidity	0.401	0.053
Outside temperature*Outside temperature	-0.822	0.004
Outside Relative Humidity*Outside Relative Humidity	0.545	0.011
CO2*CO2		
Sound*Sound		
Light*Light		

VOC*VOC	-0.391	0.148
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.658	0.009
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.332	0.169
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.776	0.022
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC	0.347	0.197
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.943	0.028
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2	-0.611	0.218
Outside temperature*Sound	1.053	0.064
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	2.68	0.171
Outside temperature*Do you sit near (wall type):		
Outside Relative Humidity*CO2	-0.798	0.040
Outside Relative Humidity*Sound	1.120	0.004
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace	1.915	0.185
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.434	0.129

CO2*VOC	-0.489	0.084
CO2*Kind of Workspace	-0.667	0.005
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.338	0.171
Sound*Kind of Workspace	-0.605	0.009
Sound*Do you sit near (wall type):		
Light*VOC	0.563	0.035
Light*Kind of Workspace	2.12	0.006
Light*Do you sit near (wall type):		
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	-0.774	0.001
S		0.626727
R-sq		75.44%
R-sq(adj)		70.49%
R-sq(pred)		65.07%
	-----Step 30-----	
	Coef	P
Constant	3.402	
Temperature	0.199	0.544
Relative Humidity	-0.882	0.000
Outside temperature	1.278	0.004
Outside Relative Humidity	0.779	0.014
CO2	0.007	0.976
Sound	-0.442	0.152
Light	-0.326	0.437
VOC	0.198	0.453
Kind of Workspace	-1.062	0.115
Do you sit near (wall type):	-0.3177	0.005
Temperature*Temperature	-3.483	0.000
Relative Humidity*Relative Humidity	0.415	0.045
Outside temperature*Outside temperature	-0.887	0.002

Outside Relative Humidity*Outside Relative Humidity	0.603	0.004
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC	-0.416	0.123
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.737	0.002
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.352	0.158
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.851	0.011
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC	0.358	0.183
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.965	0.026
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2		
Outside temperature*Sound	0.773	0.137
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	2.41	0.196
Outside temperature*Do you sit near (wall type):		
Outside Relative Humidity*CO2	-0.439	0.087
Outside Relative Humidity*Sound	0.923	0.009
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		

Outside Relative Humidity*Kind of Workspace	1.631	0.270
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.451	0.115
CO2*VOC	-0.515	0.068
CO2*Kind of Workspace	-0.787	0.003
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.338	0.170
Sound*Kind of Workspace	-0.628	0.006
Sound*Do you sit near (wall type):		
Light*VOC	0.580	0.030
Light*Kind of Workspace	2.11	0.006
Light*Do you sit near (wall type):		
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.803	0.001
S		0.627265
R-sq		75.31%
R-sq(adj)		70.44%
R-sq(pred)		64.89%
	-----Step 31-----	
	Coef	P
Constant	3.508	
Temperature	0.069	0.815
Relative Humidity	-0.883	0.000
Outside temperature	0.877	0.013
Outside Relative Humidity	0.321	0.099
CO2	-0.025	0.908
Sound	-0.149	0.580
Light	-0.316	0.452
VOC	0.283	0.274
Kind of Workspace	-0.666	0.333

Do you sit near (wall type):	-0.3054	0.007
Temperature*Temperature	-3.527	0.000
Relative Humidity*Relative Humidity	0.424	0.039
Outside temperature*Outside temperature	-0.884	0.002
Outside Relative Humidity*Outside Relative Humidity	0.563	0.007
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC	-0.383	0.156
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.707	0.004
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace	1.811	0.263
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.874	0.008
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC	0.303	0.255
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.985	0.009
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2		
Outside temperature*Sound	0.608	0.221
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	-1.380	0.016
Outside temperature*Do you sit near (wall type):		

Outside Relative Humidity*CO2	-0.289	0.243
Outside Relative Humidity*Sound	0.715	0.022
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace		
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.436	0.126
CO2*VOC	-0.374	0.175
CO2*Kind of Workspace	-1.027	0.003
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.357	0.143
Sound*Kind of Workspace	1.208	0.004
Sound*Do you sit near (wall type):		
Light*VOC	0.634	0.017
Light*Kind of Workspace	2.03	0.004
Light*Do you sit near (wall type):		
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.814	0.002
S		0.628484
R-sq		74.89%
R-sq(adj)		70.33%
R-sq(pred)		63.93%
	-----Step 32-----	
	Coef	P
Constant	3.577	
Temperature	-0.431	0.001
Relative Humidity	-0.922	0.000
Outside temperature	1.091	0.001
Outside Relative Humidity	0.316	0.093
CO2	0.034	0.874

Sound	-0.199	0.442
Light	-0.053	0.889
VOC	0.316	0.222
Kind of Workspace	-0.875	0.539
Do you sit near (wall type):	-0.3296	0.001
Temperature*Temperature	-3.494	0.000
Relative Humidity*Relative Humidity	0.424	0.038
Outside temperature*Outside temperature	-0.932	0.001
Outside Relative Humidity*Outside Relative Humidity	0.526	0.011
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC	-0.304	0.254
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.680	0.003
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace		
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.924	0.005
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC	0.285	0.285
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-0.999	0.010
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2		
Outside temperature*Sound	0.784	0.108

Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	1.509	0.038
Outside temperature*Do you sit near (wall type):		
Outside Relative Humidity*CO2	-0.313	0.197
Outside Relative Humidity*Sound	0.774	0.011
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace		
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.377	0.185
CO2*VOC	-0.320	0.244
CO2*Kind of Workspace	-1.064	0.001
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.420	0.083
Sound*Kind of Workspace	1.298	0.004
Sound*Do you sit near (wall type):		
Light*VOC	0.635	0.016
Light*Kind of Workspace	1.48	0.020
Light*Do you sit near (wall type):		
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.906	0.001
S		0.629769
R-sq		74.46%
R-sq(adj)		70.21%
R-sq(pred)		64.14%
	-----Step 33-----	
	Coef	P
Constant	3.605	
Temperature	-0.432	0.001

Relative Humidity	-0.842	0.000
Outside temperature	1.081	0.001
Outside Relative Humidity	0.326	0.083
CO2	0.083	0.694
Sound	-0.191	0.462
Light	-0.069	0.854
VOC	0.338	0.190
Kind of Workspace	-0.839	0.567
Do you sit near (wall type):	-0.3373	0.001
Temperature*Temperature	-3.519	0.000
Relative Humidity*Relative Humidity	0.404	0.047
Outside temperature*Outside temperature	-0.936	0.001
Outside Relative Humidity*Outside Relative Humidity	0.520	0.012
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC	-0.368	0.157
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.683	0.002
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace		
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.907	0.006
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC		
Relative Humidity*Kind of Workspace		

Relative Humidity*Do you sit near (wall type):	-1.048	0.007
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2		
Outside temperature*Sound	0.742	0.127
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	1.442	0.044
Outside temperature*Do you sit near (wall type):		
Outside Relative Humidity*CO2	-0.296	0.222
Outside Relative Humidity*Sound	0.760	0.013
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace		
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.385	0.175
CO2*VOC	-0.431	0.090
CO2*Kind of Workspace	-1.078	0.001
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.416	0.086
Sound*Kind of Workspace	1.251	0.003
Sound*Do you sit near (wall type):		
Light*VOC	0.606	0.021
Light*Kind of Workspace	1.42	0.018
Light*Do you sit near (wall type):		
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.940	0.001
S		0.629917
R-sq		74.37%
R-sq(adj)		70.19%
R-sq(pred)		64.20%

	-----Step 34-----	
	Coef	P
Constant	3.601	
Temperature	-0.427	0.001
Relative Humidity	-0.831	0.000
Outside temperature	1.187	0.000
Outside Relative Humidity	0.431	0.010
CO2	0.181	0.355
Sound	-0.247	0.333
Light	-0.131	0.726
VOC	0.304	0.236
Kind of Workspace	-0.966	0.421
Do you sit near (wall type):	-0.3435	0.001
Temperature*Temperature	-3.509	0.000
Relative Humidity*Relative Humidity	0.421	0.038
Outside temperature*Outside temperature	-0.998	0.000
Outside Relative Humidity*Outside Relative Humidity	0.530	0.010
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC	-0.330	0.201
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.667	0.003
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace		
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.908	0.006
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		

Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC		
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-1.057	0.004
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2		
Outside temperature*Sound	0.716	0.141
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	1.741	0.028
Outside temperature*Do you sit near (wall type):		
Outside Relative Humidity*CO2		
Outside Relative Humidity*Sound	0.631	0.027
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace		
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.410	0.149
CO2*VOC	-0.434	0.088
CO2*Kind of Workspace	-1.027	0.001
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.439	0.070
Sound*Kind of Workspace	1.107	0.006
Sound*Do you sit near (wall type):		
Light*VOC	0.578	0.027
Light*Kind of Workspace	1.23	0.012
Light*Do you sit near (wall type):		
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	0.928	0.001

S		0.630419
R-sq		74.25%
R-sq(adj)		70.14%
R-sq(pred)		64.43%
	-----Step 35-----	
	Coef	P
Constant	3.580	
Temperature	-0.417	0.002
Relative Humidity	-0.866	0.000
Outside temperature	1.218	0.000
Outside Relative Humidity	0.440	0.009
CO2	0.160	0.413
Sound	-0.256	0.317
Light	-0.115	0.758
VOC	0.153	0.503
Kind of Workspace	-0.983	0.429
Do you sit near (wall type):	-0.3266	0.001
Temperature*Temperature	-3.544	0.000
Relative Humidity*Relative Humidity	0.424	0.037
Outside temperature*Outside temperature	-1.021	0.000
Outside Relative Humidity*Outside Relative Humidity	0.521	0.011
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC		
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.645	0.004
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace		

Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.945	0.004
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC		
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-1.066	0.005
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2		
Outside temperature*Sound	0.793	0.100
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	1.788	0.035
Outside temperature*Do you sit near (wall type):		
Outside Relative Humidity*CO2		
Outside Relative Humidity*Sound	0.648	0.023
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace		
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light	-0.369	0.191
CO2*VOC	-0.405	0.110
CO2*Kind of Workspace	-1.016	0.001
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.512	0.030
Sound*Kind of Workspace	1.155	0.007
Sound*Do you sit near (wall type):		
Light*VOC	0.585	0.025
Light*Kind of Workspace	1.27	0.019

Light*Do you sit near (wall type):		
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	1.033	0.001
S		0.631063
R-sq		74.11%
R-sq(adj)		70.08%
R-sq(pred)		64.34%
	-----Step 36-----	
	Coef	P
Constant	3.556	
Temperature	-0.388	0.003
Relative Humidity	-0.915	0.000
Outside temperature	1.227	0.000
Outside Relative Humidity	0.415	0.013
CO2	0.095	0.614
Sound	-0.267	0.295
Light	0.002	0.995
VOC	0.195	0.388
Kind of Workspace	-0.976	0.390
Do you sit near (wall type):	-0.3321	0.001
Temperature*Temperature	-3.575	0.000
Relative Humidity*Relative Humidity	0.410	0.044
Outside temperature*Outside temperature	-1.057	0.000
Outside Relative Humidity*Outside Relative Humidity	0.535	0.009
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC		
Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.601	0.007

Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace		
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	0.980	0.003
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC		
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-1.152	0.003
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2		
Outside temperature*Sound	0.823	0.088
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	1.777	0.026
Outside temperature*Do you sit near (wall type):		
Outside Relative Humidity*CO2		
Outside Relative Humidity*Sound	0.630	0.027
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace		
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light		
CO2*VOC	-0.372	0.141
CO2*Kind of Workspace	-1.051	0.000
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.503	0.033

Sound*Kind of Workspace	1.106	0.007
Sound*Do you sit near (wall type):		
Light*VOC	0.672	0.008
Light*Kind of Workspace	1.13	0.009
Light*Do you sit near (wall type):		
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	1.121	0.001
S		0.631780
R-sq		73.97%
R-sq(adj)		70.02%
R-sq(pred)		64.47%
	-----Step 37-----	
	Coef	P
Constant	3.486	
Temperature	-0.333	0.008
Relative Humidity	-0.905	0.000
Outside temperature	1.266	0.000
Outside Relative Humidity	0.421	0.012
CO2	-0.001	0.994
Sound	-0.316	0.213
Light	-0.058	0.873
VOC	0.355	0.073
Kind of Workspace	-0.984	0.323
Do you sit near (wall type):	-0.3209	0.001
Temperature*Temperature	-3.574	0.000
Relative Humidity*Relative Humidity	0.401	0.049
Outside temperature*Outside temperature	-1.044	0.000
Outside Relative Humidity*Outside Relative Humidity	0.544	0.008
CO2*CO2		
Sound*Sound		
Light*Light		
VOC*VOC		

Temperature*Relative Humidity		
Temperature*Outside temperature		
Temperature*Outside Relative Humidity		
Temperature*CO2	-0.527	0.015
Temperature*Sound		
Temperature*Light		
Temperature*VOC		
Temperature*Kind of Workspace		
Temperature*Do you sit near (wall type):		
Relative Humidity*Outside temperature	1.005	0.002
Relative Humidity*Outside Relative Humidity		
Relative Humidity*CO2		
Relative Humidity*Sound		
Relative Humidity*Light		
Relative Humidity*VOC		
Relative Humidity*Kind of Workspace		
Relative Humidity*Do you sit near (wall type):	-1.125	0.002
Outside temperature*Outside Relative Humidity		
Outside temperature*CO2		
Outside temperature*Sound	0.881	0.068
Outside temperature*Light		
Outside temperature*VOC		
Outside temperature*Kind of Workspace	1.864	0.019
Outside temperature*Do you sit near (wall type):		
Outside Relative Humidity*CO2		
Outside Relative Humidity*Sound	0.687	0.015
Outside Relative Humidity*Light		
Outside Relative Humidity*VOC		
Outside Relative Humidity*Kind of Workspace		
Outside Relative Humidity*Do you sit near (wall type):		
CO2*Sound		
CO2*Light		
CO2*VOC		

CO2*Kind of Workspace	-0.878	0.001
CO2*Do you sit near (wall type):		
Sound*Light		
Sound*VOC	0.452	0.053
Sound*Kind of Workspace	0.915	0.013
Sound*Do you sit near (wall type):		
Light*VOC	0.659	0.009
Light*Kind of Workspace	0.84	0.009
Light*Do you sit near (wall type):		
VOC*Kind of Workspace		
VOC*Do you sit near (wall type):	1.179	0.001
S		0.632955
R-sq		73.79%
R-sq(adj)		69.90%
R-sq(pred)		64.62%

a to remove = 0.1
If a term has more than one coefficient, the largest in magnitude is shown.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value
Model	47	357.548	7.607	18.99
Linear	15	22.688	1.513	3.78
Temperature	1	2.847	2.847	7.11
Relative Humidity	1	7.036	7.036	17.56
Outside temperature	1	6.236	6.236	15.56
Outside Relative Humidity	1	2.568	2.568	6.41
CO2	1	0.000	0.000	0.00
Sound	1	0.624	0.624	1.56
Light	1	0.010	0.010	0.03
VOC	1	1.292	1.292	3.22
Kind of Workspace	4	1.879	0.470	1.17
Do you sit near (wall type):	3	6.440	2.147	5.36

Square	4	152.947	38.237	95.44
Temperature*Temperature	1	147.550	147.550	368.29
Relative Humidity*Relative Humidity	1	1.561	1.561	3.90
Outside temperature*Outside temperature	1	5.968	5.968	14.90
Outside Relative Humidity*Outside Relative Humidity	1	2.822	2.822	7.04
2-Way Interaction	28	37.072	1.324	3.30
Temperature*CO2	1	2.403	2.403	6.00
Relative Humidity*Outside temperature	1	3.802	3.802	9.49
Relative Humidity*Do you sit near (wall type):	3	6.024	2.008	5.01
Outside temperature*Sound	1	1.345	1.345	3.36
Outside temperature*Kind of Workspace	4	4.778	1.194	2.98
Outside Relative Humidity*Sound	1	2.373	2.373	5.92
CO2*Kind of Workspace	4	8.210	2.053	5.12
Sound*VOC	1	1.511	1.511	3.77
Sound*Kind of Workspace	4	5.154	1.289	3.22
Light*VOC	1	2.731	2.731	6.82
Light*Kind of Workspace	4	5.489	1.372	3.43
VOC*Do you sit near (wall type):	3	6.551	2.184	5.45
Error	317	127.000	0.401	
Lack-of-Fit	313	126.000	0.403	1.61
Pure Error	4	1.000	0.250	
Total	364	484.548		

Source	P-Value
Model	0.000
Linear	0.000
Temperature	0.008
Relative Humidity	0.000
Outside temperature	0.000
Outside Relative Humidity	0.012

CO2	0.994
Sound	0.213
Light	0.873
VOC	0.073
Kind of Workspace	0.323
Do you sit near (wall type):	0.001
Square	0.000
Temperature*Temperature	0.000
Relative Humidity*Relative Humidity	0.049
Outside temperature*Outside temperature	0.000
Outside Relative Humidity*Outside Relative Humidity	0.008
2-Way Interaction	0.000
Temperature*CO2	0.015
Relative Humidity*Outside temperature	0.002
Relative Humidity*Do you sit near (wall type):	0.002
Outside temperature*Sound	0.068
Outside temperature*Kind of Workspace	0.019
Outside Relative Humidity*Sound	0.015
CO2*Kind of Workspace	0.001
Sound*VOC	0.053
Sound*Kind of Workspace	0.013
Light*VOC	0.009
Light*Kind of Workspace	0.009
VOC*Do you sit near (wall type):	0.001
Error	
Lack-of-Fit	0.352
Pure Error	
Total	

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.632955	73.79%	69.90%	64.62%

Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF

Constant	3.486	0.186	18.72	0.000	
Temperature	-0.333	0.125	-2.67	0.008	2.47
Relative Humidity	-0.905	0.216	-4.19	0.000	7.45
Outside temperature	1.266	0.321	3.95	0.000	9.40
Outside Relative Humidity	0.421	0.166	2.53	0.012	4.91
CO2	-0.001	0.177	-0.01	0.994	5.09
Sound	-0.316	0.253	-1.25	0.213	11.51
Light	-0.058	0.362	-0.16	0.873	22.96
VOC	0.355	0.198	1.80	0.073	4.89
Kind of Workspace					
1	0.100	0.274	0.37	0.715	8.26
2	0.333	0.190	1.76	0.080	10.43
3	0.333	0.216	1.54	0.125	10.34
4	-0.984	0.548	-1.80	0.073	17.97
Do you sit near (wall type):					
1	0.110	0.168	0.66	0.512	7.59
2	0.1492	0.0913	1.63	0.103	5.63
3	0.061	0.112	0.55	0.586	5.94
Temperature*Temperature	-3.574	0.186	-19.19	0.000	1.72
Relative Humidity*Relative Humidity	0.401	0.203	1.97	0.049	1.40
Outside temperature*Outside temperature	-1.044	0.270	-3.86	0.000	3.86
Outside Relative Humidity*Outside Relative Humidity	0.544	0.205	2.65	0.008	3.16
Temperature*CO2	-0.527	0.215	-2.45	0.015	2.21

Relative Humidity*Outside temperature	1.005	0.326	3.08	0.002	4.60
Relative Humidity*Do you sit near (wall type):					
1	-1.125	0.412	-2.73	0.007	10.64
2	0.544	0.183	2.98	0.003	4.06
3	0.554	0.213	2.60	0.010	4.06
Outside temperature*Sound	0.881	0.481	1.83	0.068	12.36
Outside temperature*Kind of Workspace					
1	-0.401	0.427	-0.94	0.348	5.27
2	-0.466	0.297	-1.57	0.117	9.90
3	0.136	0.309	0.44	0.661	5.94
4	1.864	0.901	2.07	0.039	14.83
Outside Relative Humidity*Sound	0.687	0.282	2.43	0.015	4.55
CO2*Kind of Workspace					
1	0.297	0.273	1.09	0.278	2.52
2	-0.515	0.206	-2.49	0.013	5.95
3	0.480	0.244	1.96	0.051	4.18
4	-0.878	0.380	-2.31	0.022	2.21
Sound*VOC	0.452	0.233	1.94	0.053	2.03
Sound*Kind of Workspace					
1	-0.375	0.370	-1.01	0.312	3.58
2	0.084	0.210	0.40	0.690	5.28
3	-0.857	0.292	-2.94	0.004	2.42
4	0.915	0.528	1.73	0.084	5.17
Light*VOC	0.659	0.252	2.61	0.009	3.24
Light*Kind of Workspace					
1	-0.098	0.493	-0.20	0.843	3.55

2	0.239	0.362	0.66	0.509	15.04
3	-0.648	0.386	-1.68	0.094	6.98
4	0.84	1.25	0.67	0.502	17.05
VOC*Do you sit near (wall type):					
1	1.179	0.527	2.24	0.026	16.87
2	-0.841	0.226	-3.73	0.000	8.11
3	-0.295	0.270	-1.09	0.274	7.34

Regression Equation in Uncoded Units

Thermal Comfort = -52.08 + 5.666 Temperature - 0.1318 Relative Humidity
- 0.015 Outside temperature - 0.0836 Outside Relative Humidity
+ 0.00637 CO2 - 0.2088 Sound - 0.00460 Light - 0.0468 VOC
+ 1.53 Kind of Workspace_1 + 1.536 Kind of Workspace_2
+ 2.79 Kind of Workspace_3 - 6.17 Kind of Workspace_4
+ 0.32 Kind of Workspace_5 + 0.37 Do you sit near (wall type):_1
+ 0.424 Do you sit near (wall type):_2
- 0.484 Do you sit near (wall type):_3
- 0.307 Do you sit near (wall type):_4 -
0.11728 Temperature*Temperature
+ 0.000460 Relative Humidity*Relative Humidity
- 0.003066 Outside temperature*Outside temperature
+ 0.000363 Outside Relative Humidity*Outside Relative Humidity
- 0.000270 Temperature*CO2
+ 0.001846 Relative Humidity*Outside temperature
- 0.0381 Relative Humidity*Do you sit near (wall type):_1
+ 0.01842 Relative Humidity*Do you sit near (wall type):_2
+ 0.01876 Relative Humidity*Do you sit near (wall type):_3
+ 0.00094 Relative Humidity*Do you sit near (wall type):_4
+ 0.00313 Outside temperature*Sound
- 0.0217 Outside temperature*Kind of Workspace_1
- 0.0252 Outside temperature*Kind of Workspace_2
+ 0.0074 Outside temperature*Kind of Workspace_3
+ 0.1010 Outside temperature*Kind of Workspace_4
- 0.0614 Outside temperature*Kind of Workspace_5
+ 0.001164 Outside Relative Humidity*Sound
+ 0.000838 CO2*Kind of Workspace_1 -

0.001454 CO2*Kind of Workspace_2
+ 0.001355 CO2*Kind of Workspace_3 -
0.00248 CO2*Kind of Workspace_4
+ 0.00174 CO2*Kind of Workspace_5 + 0.000736 Sound*VOC
- 0.0246 Sound*Kind of Workspace_1
+ 0.0055 Sound*Kind of Workspace_2
- 0.0562 Sound*Kind of Workspace_3
+ 0.0600 Sound*Kind of Workspace_4
+ 0.0154 Sound*Kind of Workspace_5 + 0.000073 Light*VOC
- 0.00044 Light*Kind of Workspace_1
+ 0.00107 Light*Kind of Workspace_2
- 0.00290 Light*Kind of Workspace_3
+ 0.00376 Light*Kind of Workspace_4
- 0.00150 Light*Kind of Workspace_5
+ 0.0293 VOC*Do you sit near (wall type):_1
- 0.02088 VOC*Do you sit near (wall type):_2
- 0.00733 VOC*Do you sit near (wall type):_3
- 0.00107 VOC*Do you sit near (wall type):_4